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PAMPHLETS

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SOILS

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FERTILIZERS. Agricultural College

CO-OPERATIVE EXPERIMENTING

AS A MEANS, OF

STUDYING THE EFFECTS OF FERTILIZERS

AND THE

FEEDING CAPACITIES OF PLANTS.

By PROF. W. O. ATWATER.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
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DEPARTMENT OF AGRICULTURE,
Washington, D. C., March 27, 1882.

SIR: I submit for your consideration the following suggestions with regard to plants and fertilizers, which were laid before this department by Professor Atwater at the agricultural convention held here in January last.

I consider it very important that these suggestions should be put to a practical test, and I shall feel under great obligations if you will establish a series of experiments upon the plants and fertilizers herein enumerated, and will submit a report thereon to the department with as much care and elaboration as you can without interfering with your duties or with the work which you have assigned yourself.

Very respectfully,

GEO. B. LORING,
Commissioner of Agriculture.

*Mr. Laurence Valentine
Mountainville
Orange County
N. Y.*

CO-OPERATIVE EXPERIMENTING

AS A

MEANS OF STUDYING THE EFFECTS OF FERTILIZERS AND THE FEEDING CAPACITIES OF PLANTS.

BY PROF. W. O. ATWATER.

Farmers, from Canada to Texas, are spending millions upon millions of dollars every year for guano, fish scrap, ammoniated superphosphates, nitrate of soda, and the like. Ostensibly, they are buying the fertilizers at from \$20 to \$100 per ton. Actually, they are buying nitrogen at from 15 to 40 cents per pound. But need the farmer spend so much for nitrogen? Or might he use more with profit? These are questions that no professor of agriculture can answer. Indeed, no chemist or botanist to-day can so much as tell him how the different plants he cultivates stand related to nitrogen, for what ones he must buy it, and what ones he may use in his rotation to gather it from nature's stores and furnish it to him without money and without price save the cost of tillage.

The question of the nitrogen supply is only one of a great many whose solution is most urgently demanded. We must know how to feed our plants, or go without food ourselves. We need more light. Some must come from the laboratory and the greenhouse; some must be sought in the field.

Field experiments rationally planned, carefully carried out, faithfully reported, and interpreted with the aid of the most advanced science, will carry us far toward finding out many of these things which we so much want to know. If along with these we can have proper studies, chemical and physical, of the soils experimented upon, analyses of the plants produced, and in addition pot experiments whose conditions can be definitely known and controlled, and especially if we can work together we may hope for the information we need.

Five years ago, while director of the Connecticut Agricultural Experiment Station, I suggested some field experiments with fertilizers to be carried out by farmers for the purpose of studying the needs of their soils and the best materials to supply them. The outgrowth of these, in the form of extended series of experiments during four successive seasons, has been stated briefly in the *American Agriculturist*, and, in more detail, in the Reports of the Connecticut Board of Agriculture

for 1877, 1878, 1879, and 1880. The experiments of 1881 have not yet been published in detail, but a few of the more important results will be given herewith.

With the sets of experimental fertilizers were sent blanks on which any who should choose were invited to send reports of their experiments. Nearly three hundred experiments have been reported. They come from colleges, experiment stations, and individual farmers in all the States east, and from some west of the Mississippi, and from several of the British provinces. The quality of the work as indicated by the reports is most gratifying.

The experiments have been of two classes. The first, which may be called general experiments, are of a simpler sort, and intended primarily for soil tests, involve the use of eight or more different kinds and mixtures of fertilizing materials containing nitrogen, phosphoric acid, and potash. The second class, the "special nitrogen experiments", have been of more complicated character, and have had for their object the study of the feeding capacities of some of our more common cultivated plants, with special reference to the nitrogen supply.

It is to these latter experiments that attention is especially invited here.

THE FEEDING CAPACITIES OF PLANTS.

The experiments we are discussing bring us face to face with one of the most important problems with which agricultural chemistry has to deal, and at the same time throw some new light upon it. I refer to what may, perhaps, be most properly called the feeding capacities of plants, their power of gathering their supplies of food from soil and air, and the effects of the artificial supply of different ingredients of plant-food upon their growth.

A vast deal of experience in the laboratory and in the field bears concurrent testimony to the fact, though we are still deplorably in the dark as to how or why it is so, that different kinds of plants have different capacities for making use of the stores of food that soil and air contain. Of the ingredients of plant food in our soils, the most important, because the most costly, is nitrogen. Leguminous crops, like clover, do somehow or other gather a good supply of nitrogen where cereals, such as wheat, barley, rye, and oats would half starve for lack of it, and this in the face of the fact that leguminous plants contain a great deal of nitrogen, and cereals relatively little. Hence a heavy nitrogenous manuring may pay well for wheat and be in large part lost on clover.

NEED OF MORE INFORMATION.

Hitherto we have been compelled to rely mainly upon European investigations for our facts regarding the nutrition of plants and the action of manures. Our information is incomplete, and even the foremost teachers may give us wrong counsel.

Dr. J. B. Lawes, of Rothamsted, England, unquestionably the fore-

most field experimenter in the world, in writing, in 1873, to the treasurer of the Massachusetts Society for the Promotion of Agriculture, said: "The best possible manure for all graminaceous crops—wheat, barley, maize (corn), oats, sugar-cane, rice, and pasture grass—is a mixture of superphosphate and nitrate of soda. * * * Potash is generally found in sufficient quantities in soils, and the artificial supply is not required." In more than half of our experiments with corn, and in nearly all with potatoes, the crops have been materially aided by potash salts, and without potash in the fertilizer they have often failed. The mixture which Dr. Lawes regards as "the best possible manure" for corn was sometimes very useful and sometimes brought almost no return. The potash, which his experience in England led him to consider superfluous, was here, in many cases, the most necessary of all the fertilizing ingredients.

Several years ago the professor of agriculture of one of our leading agricultural colleges proposed a series of formulas for different crops. With the rest was one for corn, which, with a moderate proportion of potash and a small amount of phosphoric acid, supplied nitrogen at the rate of 64 pounds, and at a cost of over \$15 per acre. Later, a well-known writer upon agricultural science has enthusiastically advocated the culture of corn with chemicals, recommending for the purpose, and using in an extensive series of experiments upon his own farm, a fertilizer which supplied nitrogen at the rate of 90 pounds, and at a cost of \$18 to \$20 per acre. Both of these gentlemen thus assumed that to raise corn successfully would require large and costly supplies of nitrogen. The question whether corn can gather its own nitrogen, like clover, or demands an artificial supply, like wheat, whether it is an "exhausting" or a "renovating" crop, has been much discussed. Upon its answer depends the success of corn-growing in our older States. The experiments referred to bear emphatic testimony upon this point. The corn has almost uniformly refused to respond to nitrogen in fertilizers, and persists in getting on well without any artificial supply. But it has been largely benefited by phosphoric acid, and often by potash. The formulas above, with their large and excessively expensive amounts of nitrogen, would, in nearly every case, have involved great waste of both fertilizer and money.

EXPERIMENTS UPON THE EFFECTS OF NITROGENOUS FERTILIZERS.

One of the ways in which co-operative field experiments may aid in the solution of these problems may be illustrated by citing some of the details of the series of experiments upon the effect of nitrogen in fertilizers which were referred to above, and which have been performed by a number of professors in agricultural colleges and practical farmers, with what seems to me most gratifying success.

The specific questions to be studied may be stated thus:

1st. How do the plants experimented with get on with the "mineral" fertilizers, such as are supplied by superphosphates and potash salts?

2d. More especially, how do they respond to nitrogen when added, in different forms and amounts, to the mineral fertilizers?

3d. And finally, what inferences may we draw as to the feeding capacities of the plants, their power to gather their food from soil and air, and the effects of different materials upon their growth, especial reference being made to the nitrogen supply?

For the systematic study of these questions a special "nitrogen experiment" was devised in 1878, and conducted by several gentlemen. Similar series were repeated in 1879, and with some variations in 1880 and 1881.

The idea was to compare the effects of mineral fertilizers (superphosphate and potash salt) alone, and the same with nitrogen in different amounts and forms. The plan is explained in the following extract from a circular sent to the experimenters:

The Object of this experiment is to test the effects of nitrogenous fertilizers in different amounts and combinations upon the growth of the plant, and inferentially its capacity to gather its nitrogen from natural sources.

The Fertilizers.—The ingredients and amounts are such as are used in ordinary practice, phosphoric acid and potash being supplied in about the proportions that occur in a corn crop of fifty or sixty bushels, and nitrogen in one-third, two-thirds, and full amount in same crop.

Forms of Nitrogen.—The nitrogen is supplied as nitric acid in nitrate of soda; as ammonia in sulphate of ammonia, and as organic nitrogen in dried blood.

Quantities of Nitrogen.—The nitrogen is supplied at the rate of twenty-four pounds per acre in "one-third ration"; forty-eight pounds per acre in "two-thirds ration"; and seventy-two pounds per acre in "full ration".

Arrangement of Plots and Fertilizers.—The ingredients are supplied as:

Partial fertilizers,	{ Group I. Nos. 1—3. each by itself. }	Thus testing the effects of ingredients separately, and capacity of soil.
	{ Group II. Nos. 4—6. Two by two. }	
Complete fertilizers	{ Group III. Nos. 7—9. Nitrogen as nitric acid in nitrate of soda. }	{ Nitrogen in one-third, two-thirds, full ration. }
	{ Group IV. Nos. 10—12. Nitrogen as ammonia in sulphate of ammonia. }	
	{ Group V. Nos. 13—15. Nitrogen as organic nitrogen in dried blood. }	

The fertilizers were supplied, in part at cost, and in part gratuitously, by the Mapes Formula and Peruvian Guano Company of New York. Especial thanks are due to Mr. C. V. Mapes, without whose interest and enthusiasm, as well as counsel and substantial help, the enterprise could not have succeeded as it has.

The full details of the experiments are to appear in a report of the United States Department of Agriculture. The tables herewith give an outline of results of some of the experiments of the last season and will serve as illustrations. The figures are, however, much condensed and many interesting details are omitted.

TABLE I gives the results of several experiments with cotton, corn, and potatoes. The unfavorable weather which affected the majority of the experiments, has reduced the yield materially in most of these. In several the effects of unevenness of soil are manifest; on some the supply of available plant food in the soil was evidently so great as to obscure the action of the fertilizers. Those of Mr. Newton with corn

and Mr. Manning with clover, show marked exceptions to what seems to be the common rule, that these crops are not greatly aided by nitrogenous fertilizers. Indeed, all illustrate forcibly our need of more experimenting.

TABLE II shows an experiment on an older and slightly different schedule. It is interesting both because of its sharply-defined results and as an illustration of the excellent work ordinary farmers do in this line.

TABLE I. NITROGEN EXPERIMENTS, 1881.

- I. PROF. W. C. STUBBS, Alabama Agricultural and Mechanical College, Auburn, Ala.:
Soil—Worn-out pasture; level, upland, sandy, light, well-drained.
Subsoil—Reddish yellow clay. *Weather*—Dry and unfavorable.
- II. EDWARD HICKS, Old Westbury, N. Y.:
Soil—Level, sandy loam, light, dry. *Subsoil*—Yellow loam. *Previous crop*—Corn. *Weather*—Dry and unfavorable.
- III. PROF. C. L. INGERSOLL, Purdue University, La Fayette, Ind.:
Soil—Upland, level, black, similar to prairie, sticky when wet, bakes when dry; dry, well drained. *Subsoil*—Gravel. *Previous crop*—Corn. *Weather*—Very dry and unfavorable.
- IV. PROF. SAMUEL JOHNSON, Michigan Agricultural College, Lansing, Mich.:
Soil—Level, upland, sandy loam, light, drained dry. *Subsoil*—Gravelly. *Previous crop*—Corn. *Weather*—Dry, cold, unfavorable.
- V. W. C. NEWTON, Durham, Conn.:
Soil—Old meadow, hill land, dark loam. *Subsoil*—Moist. *Weather*—Unfavorable.
- VI. J. W. PIERCE, West Millbury, Mass.:
Soil—Worn-out grass land, upland, nearly level, clay loam, light, dry. *Subsoil*—Gravelly, but some clay. *Weather*—Cold and unfavorable.
- VII. C. E. THORNE, farm manager, Ohio State University, Columbus, O.:
Soil—Level, upland, clayey loam, "drift formation" from Huron shale, compact, wet before draining. *Subsoil*—Similar to surface soil, retentive. *Previous crop*—Corn, with stable manure. *Weather*—Severe drouth.
- VIII. J. M. MANNING, Taunton, Mass.:
Soil—Upland, sandy loam, loose. *Subsoil*—Yellow sand. *Previous crops*—Potatoes and corn. *Weather*—Unfavorable.

TABLE I.—EFFECTS OF NITROGENOUS FERTILIZERS.

I. Professor STUBBS, Alabama, COTTON.
 II. Mr. HICKS, New York, CORN.
 III. Professor INGERSOLL, Indiana, CORN.
 IV. Professor JOHNSON, Michigan, CORN.

V. Mr. NEWTON, Connecticut, CORN.
 VI. Mr. PIERCE, Massachusetts, CORN.
 VII. Mr. THORNE, Ohio, CORN.
 VIII. Mr. MANNING, Massachusetts, CLOVER.

Fertilizers and produce per acre.

	Number of experiment.	I. Cotton.	II. Corn.	III. Corn.	IV. Corn.	V. Corn.	VI. Corn.	VII. Corn.	VIII. Clover.
		<i>Lbs.</i>	<i>Bush.</i>	<i>Bush.</i>	<i>Bush.</i>	<i>Bush.</i>	<i>Bush.</i>	<i>Bush.</i>	<i>Lbs.</i>
Preliminary Group	0. No manure	587	16.3	38.2	44.7	12.5	10.3	40.0	480
	1. Nitrate of soda, 150 pounds	805	26.0	35.9	53.1	23.5	11.7	44.3	700
	2. Superphosphate, 300 pounds	1,162	22.8	36.4	51.2	13.8	16.0	48.6	1,200
	3. Muriate of potash, 150 pounds	564	34.5	34.5	52.0	15.0	17.7	48.6	940
	4. Nitrate of soda, 150 pounds	1,599	24.5	33.6	61.6	23.8	14.3	50.3	1,080
Nitrate of soda Group	5. Superphosphate, 300 pounds	932	29.5	34.5	43.6	23.8	23.0	44.9	560
	6. Muriate of potash, 150 pounds	1,219	28.2	34.5	59.0	13.8	34.6	52.	1,140
	7. Mixed mineral fertilizers (as No. 6)	1,541	29.0	37.3	58.8	23.3	34.0	49.1	1,200
	8. Nitrate of soda, 150 pounds	1,404	33.8	32.5	55.6	41.7	35.7	45.7	1,460
	9. Mixed mineral fertilizers	1,242	31.5	33.1	49.1	56.7	41.4	47.4	1,480
Sulphate of ammonia Group	6a. Nitrate of soda, 450 pounds	3,115	30.0	33.4	56.7	16.3	37.7	46.0	1,660
	10. Mixed mineral fertilizers (as No. 6)	1,116	27.8	36.1	55.7	28.5	39.4	41.7	1,880
	11. Sulphate of ammonia	1,265	30.8	38.4	58.9	42.5	40.3	42.3	2,000
	12. Mixed mineral fertilizers	1,162	32.5	34.0	50.4	48.3	39.4	43.4	2,400
	6b. Sulphate of ammonia		29.0	35.7	51.0		28.6	48.3	1,440
Dried blood Group	13. Mixed mineral fertilizers (as No. 6)	1,357	37.6	34.0	49.4	28.8	35.4	41.1	1,620
	14. Dried blood, 125 pounds	1,300	36.3	34.5	51.6	33.8	37.0	41.4	1,940
	15. Mixed mineral fertilizers	1,127	35.2	33.4	61.4	40.6	39.0	39.4	2,420
	6c. Dried blood, 675 pounds		39.7	33.4	57.1	20.6		40.9	1,200
	16. Farm manure	449	16.5	33.1	31.7	13.8		43.7	1,500
00. No manure								35.4	800

In Professor Stubb's experiment three plots, not mentioned in the table, had "mixed minerals" with cotton-seed meal in quantities to supply nitrogen in the same amounts as in the nitrate of soda, sulphate of ammonia, &c. The yields were, with $\frac{1}{2}$ ration 1,283.5 pounds, and with full ration, 1,345 pounds per acre.

TABLE II.—EFFECTS OF NITROGENOUS FERTILIZERS.

Experiments with oats and potatoes in 1881. By Mr. Charles Fairchild, of Middletown, Conn.

[Soil, dark loam, loam subsoil, moist; had oats in 1877, rye in 1878, grass in 1879, and corn fertilized as below in 1880.]

	Kind and amount of fertilizers per acre.	Yield per acre.			Increase per acre.			Cost of fertilizers, freight, &c.	Pecuniary results.		
		Oats.		Potatoes.	Oats.		Potatoes.		Value of increase.		Gain.
		Grain.	Straw.		Grain.	Straw.			Oats.	Potatoes.	
				Bush.			Lbs.				Bush.
0	No manure	36.9	1,180	28.0	11.3	627	13.3	\$6.00	\$9.75	\$9.98	\$3.98
1	Nitrogen mixture, 150 pounds	38.1	1,820	42.0	6.9	607	27.3	6.00	7.42	20.48	14.48
2	Superphosphate, 300 pounds	53.8	1,840	56.0	6.9	527	31.3	3.75	5.50	23.48	17.75
3	Muriate of potash, 150 pounds	31.3	1,720	60.0	4.4	527	31.3	3.75	5.50	23.48	17.75
4	Nitrogen mixture, 150 pounds, and superphosphate, 300 pounds	51.9	2,660	94.7	25.0	1,467	66.0	12.00	22.55	49.50	37.50
5	Nitrogen mixture, 150 pounds, and muriate of potash, 150 pounds	42.5	2,160	68.0	15.6	967	39.3	9.75	14.40	29.48	4.65
6	Superphosphate, 300 pounds, and mur. of pot., 150 pounds, "mixed minerals"	33.8	2,280	90.7	6.9	1,087	62.0	9.75	10.30	46.50	36.75
7	Mixed minerals (as No. 6), 450 pounds, and nitrate of soda, 150 pounds	54.4	3,500	124.7	27.5	2,307	96.0	15.75	28.97	72.00	54.25
8	Mixed minerals, 450 pounds, and nitrate of soda, 300 pounds	59.4	3,860	138.7	32.5	2,667	110.0	21.75	33.88	82.50	60.75
9	Mixed minerals, 450 pounds, and nitrate of soda, 450 pounds	59.4	4,380	120.0	32.5	3,107	91.3	27.75	36.52	68.40	40.65
6a	Mixed minerals (as No. 6), 450 pounds	35.3	1,760	94.0	9.4	567	65.3	9.75	8.56	48.93	39.23
00	No manure	27.5	1,280	46.7	25.0	1,947	94.0	15.75	25.43	70.50	54.75
10	Mixed minerals, 450 pounds, and nitrogen mixture, 150 pounds	51.9	3,140	122.7	28.8	2,187	116.0	21.75	28.93	87.00	65.25
11	Mixed minerals, 450 pounds, and nitrogen mixture, 300 pounds	55.6	3,380	144.7	32.5	2,587	116.0	27.75	33.40	87.00	65.25
12	Mixed minerals, 450 pounds, and nitrogen mixture, 450 pounds	33.8	1,760	110.0	6.9	567	81.3	9.75	7.18	60.98	51.23
6b	Mixed minerals (as No. 6), 450 pounds	61.9	3,700	135.3	35.0	2,507	106.6	21.75	34.29	79.95	58.20
13	Mixed minerals, 450 pounds, and sulphate of ammonia, 225 pounds	53.8	3,080	134.7	26.9	1,887	106.0	21.75	26.10	79.50	57.75
14	Mixed minerals, 450 pounds, and dried blood, 450 pounds	54.4	2,980	133.3	27.5	1,787	104.6	21.75	25.85	78.45	4.10
15	Peruvian guano, 450 pounds, and muriate of potash, 150 pounds	35.0	1,760	96.0	8.1	567	67.3	9.75	7.87	50.48	40.73
16	Mixed minerals (as No. 6), 450 pounds	26.3	1,120	29.3	4.4	487	25.3	3.00	5.33	18.98	15.98
030	No manure	31.3	1,680	54.0	8.1	767	45.3	5.50	9.07	33.98	23.48
A	Bone, 150 pounds	35.0	1,960	74.0	18.8	787	78.7	10.75	15.03	4.28	4.28
B	Bone, 150 pounds, and muriate of potash, 100 pounds										
C	Same as B, and sulphate of ammonia, 100 pounds										

The plots were parallel strips of eight square rods each. In 1880 corn was planted over the whole field. In 1881 the whole was divided into halves by a line crossing the plots, and one-half devoted to oats and the other half to potatoes. Mr. Fairchild proposes to follow with wheat and grass, thus running the experiment through a regular rotation of several years, the same fertilizers being applied to the same plots year after year, while the crops succeed each other as in ordinary farm practice. The cost of the fertilizers includes \$6 per ton for freight and applying. Potatoes are estimated at 75 cents per bushel, oats at 55 cents, and oat straw at \$12 per ton, which are fair rates for the region and season.

The variety of results in the different experiments is very striking. Mr. W. I. Bartholomew, of Putnam, Conn., has been conducting the nitrogen experiments with corn and potatoes for three years. In every trial every plot which has received phosphoric acid has given a more or less satisfactory return, and every one without phosphoric acid has failed. Nitrogen and potash have each increased the yield of corn, but neither has brought enough increase to pay its cost, and the loss has been larger or smaller as more or less was used. Potatoes, on the other hand, have responded profitably to all the ingredients.

Mr. C. Sage, of Middletown, Conn., has had a very different experience. Nitrogen has proved as inefficient on his land as on Mr. Bartholomew's. Phosphoric acid, which Mr. Bartholomew finds so effective, helps him but little, while potash is decidedly the regulating ingredient, the corn responding uniformly and largely to every application of potash salt. One hundred and fifty pounds per acre of muriate of potash, costing \$3.50, makes the difference between corn so poor as to be hardly worth the husking, and 60 bushels or more of beautiful shelled corn and a fine growth of stalks.

In the experiment of Mr. C. Newton, of Durham, Conn., given in Table I, we have a still different result. Potash is as useless as in Mr. Bartholomew's experiment. Phosphoric acid does no more good here than with Mr. Sage. But the nitrogen to which both these gentlemen's corn paid so little heed is on Mr. Newton's soil uniformly efficient. The corn responds largely and profitably to nitrogen in every form and on every plot, and the yield rises and falls regularly with the amount of nitrogen applied; I should add that in each of these cases the results are those not of a single, but of two or three years' trials. Mr. Newton's experience, however, seems to be an exception and an unusual one. Instances in which the nitrogen is absolutely harmful are much more frequent. Professor Thorne's in Table I is such an one. The corn here suffered from very severe drought, but Professor Thorne writes me that he has observed the same thing in favorable seasons, and several other reports tell the same story. Mr. J. W. Sanborn, the well-known farm superintendent and experimenter of the New Hampshire Agricultural College, has a case in which sulphate of ammonia helped the corn materially the first season, did no good the second, and "utterly demoralized" it the third.

On soils that are rich, or even in only fairly good condition, nitrogenous fertilizers, like other manures, often show very little effect. Such seems to be the case in Professor Henry's experiment in Table I.

EFFECTS OF NITROGENOUS FERTILIZERS UPON CORN.

Estimating a bushel of corn, with its cobs and stalks, to contain $1\frac{1}{2}$ of nitrogen, and to be worth 80 cents, the effects of the nitrogenous fertilizers in the special and in the general experiments may be summarized as follows, remembering that the superphosphate and potash salt,

"mixed minerals," supplied the amounts of phosphoric acid and potash in a crop of not far from 55 or 60 bushels, which would also contain about the 72 pounds of nitrogen.

In the general experiments of the mixture of 300 pounds superphosphate and 200 pounds muriate of potash brought on the average of fifty-three experiments, about $43\frac{1}{2}$ bushels of shelled corn per acre. The special experiments, however, seem to me a fairer test of what the fertilizers may do, because, while made in all sorts of weather and on worn-out soils, they were nearly all on soils and in latitudes fit for corn, as many of the general experiments were not. In these the mixture of 300 pounds superphosphate and 150 pounds of potash salt, which can be bought for \$8.25, brought, on the average, 43 bushels of shelled corn per acre. Omitting Mr. Newton's experiment, the results of which are very exceptional, the average is $44\frac{1}{2}$ bushels.

The experiments of the four seasons bear almost unanimous testimony to two things: The corn was helped but little by nitrogen in the fertilizers; and it gathered a good deal from natural sources. The increase of crop and of nitrogen in the crop will appear more clearly if we look at it another way.

In number of trials.	With nitrogen.		The average increase of corn was.	The increase of nitrogen in the crop was.
	Amount per acre.	Contained in crop of—		
	<i>Pounds.</i>	<i>Bushels.</i>	<i>Bushels.</i>	<i>Pounds.</i>
95	24	18	3.6	4.8
76	48	36	5.3	7.1
42	72	54	6.6	8.8

Or, estimating the results in dollars and cents:

In trials, total number.	With nitrogen, amounts.	Costing.	The nitrogen paid for itself in trials.	The nitrogen failed to pay for itself in trials.	The average loss in the several trials was.
95	24 lbs.	\$5 50	21	74	\$2 62
76	48 lbs.	11 00	13	63	6 76
42	72 lbs.	16 50	4	38	11 22

The only cases in which the largest rations were profitable were in the experiments of Mr. Newton.

The above calculations of pecuniary loss and gain of course apply only to those regions where corn is dear. But even at these rates the nitrogen increased the crop enough to pay its costs in only 38 trials out of 213. The pecuniary loss rose and fell with the amount of nitrogen used. With mineral fertilizers alone the crop gathered, by the above estimates, some 60 pounds of nitrogen per acre.

The important fact, however, is this: The corn plant has in these trials shown itself capable of getting on and bringing fair yields with small

amounts of the less costly mineral fertilizers, even in the worn-out soils of the Eastern States. With this help it has gathered its nitrogen from natural sources, and holds it readily to be fed out on the farm and returned in the form of manure for other crops. In other words, the experiments thus far imply that corn has, somehow or other, the power to gather a great deal of nitrogen from soil or air, or both; that in this respect it comes nearer to the legumes than the cereals; that, in short, corn may be classed with the "renovating" crops. If this is really so, and this can be settled only by continued experimenting, then our great cereal, instead of being simply a consumer of the fertility of our soils, may be used as agent for their restoration.

FEEDING CAPACITIES OF OTHER CROPS.

The results of the experiments with other crops were briefly summarized in an account given in the last report of the Connecticut board of agriculture, as follows:

Taking all in all, the potatoes responded well to the superphosphate, the potash salt, and the nitrogenous fertilizers, and the "complete fertilizer" has been most profitable in almost every case where the weather permitted fair growth. None of the other crops, except, perhaps, turnips, have shown such uniformly beneficial results from all the materials.

The experiments indicate very decidedly that the potato plant differs from many others in respect to the effect of these fertilizing materials upon its growth, and imply that it has less capacity than corn for gathering an adequate supply of food from natural sources. It seems to demand a full and immediately available supply of nourishment for its successful growth.

Concerning the other crops, the data at hand are too meager to warrant any general conclusions. * * * In general, however, the experiments accord with the common notion that makes superphosphate almost a specific for turnips. But they imply that even when the superphosphate is supplied in abundance, the turnip is not usually able to gather enough of the other materials for a full yield unless they are close at hand in readily available forms.

EXPERIMENTS WITH COTTON.

Professor Stubbs' experiment with cotton is extremely interesting. Phosphoric acid has great, and potash very little, effect. Nitrogen increases the crop, but that in cotton-seed meal is as useful, or more so, than in the other and more costly materials, nitrate of soda, sulphate of ammonia, and dried blood. This is only one of a number of experiments which Professor Stubbs has made, upon whose results, added to his general experience, he bases a number of important conclusions, among which are the following:

1. Our [Alabama] soils, which result from the disintegration of metamorphic rocks, principally feldspathic and hornblende, need a little nitrogen, much phosphoric acid, and no potash for cotton.
2. Our great want, and it seems to prevail through the older cotton States (except the black creoleons belt of Alabama, which has not been thoroughly tested), is soluble phosphoric acid. On worn-out soils a small amount of nitrogen is required. A fertilizer with 3 per cent. of nitrogen and 10 per cent. of soluble phosphoric acid, meets the demand very well.

3. Phosphoric acid hastens and nitrogen retards the maturity of the crop.

4. Cotton seed and cotton-seed meal are as effective as dried blood, sulphate of ammonia, nitrate of soda, or other nitrogenous fertilizers, and far cheaper and more economical.

To what extent and under what conditions such principles as these are applicable in the culture of cotton and other crops, are matters of vital importance in Southern agriculture. The usefulness of systematic experiments to test them needs no argument.

EFFECTS OF PHOSPHORIC ACID IN DIFFERENT FORMS OF COMBINATION.

The nitrogen supply is only one of the many questions whose solution is of vital importance to our agriculture. The relations of phosphoric acid, potash, and other ingredients of plant food, whose lack in our soils we seek to supply, at great expense, with phosphates and potash salts, demand equally full and thorough study.

Treating the insoluble phosphate of bone or mineral phosphate with acid to make superphosphate is expensive. Soluble phosphoric acid costs us from 12 to 15 cents or more per pound, while we can buy it in the insoluble forms for from 4 to 6 or 7 cents. The general theory is that superphosphate is necessary, but still, somehow or other, many of us have the feeling that, in many cases at least, the cheaper insoluble phosphates would do as well; that fine grinding might serve instead of superphosphating; and that there are many cases in which the cheap rock phosphates might replace the dearer bone manure. If so, the saving would be immense.

The Aberdeenshire Agricultural Association of Scotland, through Mr. Thomas Jamieson, F. C. S., its chemist, has been for several years past conducting an extended system of experiments in which have been studied, with other things, the effects of phosphoric fertilizers of different sorts, alone and associated with nitrogen.

The results of several years work on five typical varieties of Aberdeen soil in the ordinary state of cultivation are summarized by Mr. Jamieson in the statements.

1. That phosphates of lime decidedly increase the turnip crop, but that farmers need not trouble themselves to know whether they are of animal or mineral origin.

2. That soluble phosphate is not superior to insoluble phosphate to the extent that is generally supposed.

3. That nitrogenous manures have little effect on turnips used alone, but when used with insoluble phosphates increase the crop; that the addition of nitrogen to soluble phosphates does not seem to increase the solid or dry matter in the crop; that there is no material difference between the effects of equal quantities of nitrogen in nitrate of soda and in sulphate of ammonia.

4. That fineness of division seems nearly as effective in assisting the braird and increasing the crop as the addition of nitrogenous manures. Hence the most economical phosphoric manure for turnips is probably insoluble phosphate of lime, from any source, ground down to an impalpable powder.

Mr. G. Clendon, jr., of Buckner's Station, Va., who has carried out a series of the "general" experiments above referred to, and taken the opportunity to test finely-ground South Carolina phosphate alongside the dissolved bone-black, obtained with the raw phosphate a yield larger than with superphosphate or stable manure, and nearly as large as with the complete fertilizer. The testimony of a single experiment, of course, must always be questioned; but Mr. Clendon's results have the regularity that characterizes uniform land, and seem to be borne out by other experiments and his general experience. He writes:

My experiments have been carried on over ten years. In every year the good effect of the raw phosphate was apparent. * * * The soil is a decomposed gneiss, uniformly poor, and is a fair sample of hundreds of square miles lying between the base of the Blue Ridge and tide-water in Virginia. * * * I think the experiments should be repeated over a wider country.

On the other hand, it is a familiar fact that in the neighborhood of Charleston, S. C., where the raw phosphate is obtained, its use in the raw state has not become general, and that many attempts elsewhere to introduce insoluble phosphates have failed. When, where, and why the different forms of phosphoric acid are in place, are problems that demand thorough investigation.

WHAT IS NEEDED FOR SUCCESSFUL FIELD EXPERIMENTING.

Unless I greatly err, one of the chief causes of the failure of so much of the honest and thorough field experimenting that has been done, to accomplish its purpose has been that the questions have been too complex, while the work has not been prosecuted far enough to make it all complete.

It is by selecting specific and narrow questions, and working at them systematically and continuously, that we shall secure the most valuable results. There has been too much firing at random. We need to choose proper points of attack, be sure of our aim, and concentrate our fire until a breach is made.

CO-OPERATIVE EXPERIMENTING.

And we need not only to work rightly, but to work together. Experiments with a common object on a common plan, conducted by intelligent, careful investigators, in different places, under different but accurately observed and recorded conditions, are needed to bring the results which scientific agriculture so pressingly demands.

A letter from Professor Henry, of the agricultural department of the University of Wisconsin, says most aptly, "What we most need is *union*," and dwells upon the importance of co-operative field experiments with fertilizers, experiments which shall be "*far-reaching*" in their character.

Mr. Sanborn, of the New Hampshire Agricultural College, in alluding to the fact that most of our agricultural science hitherto has come from Europe, and that we need facts and principles of our own, says of the

work of field experimenting with fertilizers: "It is of incalculable importance to the country," and adds: "The co-operative plan is the only right thing if quick and reliable work is to be done." And unless I greatly err, these gentlemen, who, with numerous others, are showing their faith by their works, are expressing in the words just quoted a general sentiment of the men who to-day are doing most to promote agricultural science in this country.

Now it seems to me that the way to co-operate is to co operate. The way to get on is to "stay not upon the order of your going, but go." Go wisely, carefully, rationally, slowly if need be—but go.

The colleges and experiment stations of nine States, and several prominent farmers of the same and other States, have already commenced work on the schedule above explained. Six other colleges and stations have made arrangements to commence the same experiments this season, and three others are experimenting on the same question of the effects of nitrogenous fertilizers, though on somewhat different plans.

Several State agricultural reports show that the same enterprise is being considered by other official bodies as well. The secretary of the Ohio Board of Agriculture, Mr. Chamberlain, in his last report devotes a number of pages to accounts of the nitrogen experiments referred to, and suggests the study of the nitrogen supply for wheat on typical soils in his State. The last report of the commissioner of agriculture of Virginia recommends similar experiments in that State. Several other State organizations are taking steps in the same direction. Besides all these, there are numbers of intelligent farmers throughout the whole country who are able and will be more than willing to contribute most efficient work. The experiments above cited suffice to prove this beyond all doubt.

With the assured co-operation of so many representative men, including really the majority of the best-known experimenters in the country, the feasibility of co-operative experimenting is no longer a question.

APPENDIX.

In organizing a system of co-operative experimenting, to which the above address is devoted, one great need is an official and influential center, whence suggestions and plans for work may emanate, and where reports of results may be collated, arranged, and published, and with whose wise aid all can work together. By the espousal of the enterprise by the Agricultural Department at Washington, under its present very efficient management, this want is most happily met. And nothing could be more auspicious for such a union between the department and the best experimenters of the country than the discussions and action of the late convention.

PLANS FOR EXPERIMENTS.

In accordance with a request from the Commissioner of Agriculture, I have undertaken, with the aid of several well-known workers in this line, to prepare some plans for experiments; doing so, however, with the feeling that what is wanted is not detailed and inelastic schedules, but rather, outlines which each experimenter can fill in as seems to him most advisable. Every man knows his own circumstances, and every intelligent worker has valuable ideas of his own, which others have not. It seems to me that the most effective system will be one which will enable each to develop his own ideas, while we all work together and contribute our results to the common fund.

KIND OF INVESTIGATIONS THAT ARE NEEDED.

To get the most complete results we need:

I. Field experiments, to include—

- a. The culture of plants on plots of land treated with different manures, and careful weighings and measurements of produce.
- b. Where practicable, chemical and physical studies of the soil.
- c. In many cases, chemical analyses of the plants.

II. Pot experiments, in which the conditions can be definitely known and controlled, and the needed studies of soil and plants be carried out with equal or greater convenience and accuracy.

Indeed, it is safe to say that there ought to be in the various sections of the country chemical and physical surveys of the land in the behalf of agriculture, as there have been topographical and geological surveys in the behalf of other industries and interests. And in fact this is precisely the direction in which we are tending in this experimental work.

PLANS FOR FIELD EXPERIMENTS.

The subjects proposed at the Washington convention for co operative experiments were:

1. The supply of nitrogen to plants.
2. The action of phosphoric acid in different forms of combination and in different fertilizing materials upon the growth of plants.

Practically, so far as field experiments are concerned, these two subjects reduce themselves to the study of the action of nitrogenous and phosphatic fertilizers.

The first thing, then, will be to see what materials are to be employed.

Since similar questions regarding potash will naturally arise, it may be well to include brief suggestions regarding potassic fertilizers. Of course sulphuric acid, lime, and magnesia could be treated in like manner if it should hereafter become desirable.

QUANTITIES OF MATERIALS TO BE USED.

To decide what quantities of materials will be best for the purpose is not easy, because of the lack of the very data for which the experiments are, in part, to be made. Neither the proportions which occur in any crops, nor those in farm manures, could well serve as a standard. Probably the best plan will be to endeavor to select, as extremes, the smallest and the largest quantities that general experience has brought into ordinary use, and arrange intermediate quantities at proper intervals between.

Nitrogen.—A dressing of 450 pounds of nitrate of soda per acre is probably as large as would be apt to be used in this country, in ordinary practice, on ordinary crops. At the same time it is no more than has been found profitable in previous nitrogen experiments, and is perhaps as small as would be advisable for the maximum. At 16 per cent. it would contain 72 pounds of nitrogen.

Three hundred pounds of an ammoniated superphosphate with 3 per cent., or 9 pounds, of nitrogen, is not an unusual dressing per acre. As little as 200 pounds, with only 6 pounds of nitrogen per acre, is a common quantity for cotton, and indeed, for other crops, when applied in the hill or drill or as a supplement to other manures. Six pounds of nitrogen is a very small quantity for an acre of land. Twelve pounds, which would be contained in 75 pounds of nitrate of soda, would seem to be little enough. Still, it will be well to provide for as small an amount as is ordinarily used.

In arranging the rations it would seem best to make the difference between the smaller rations less than that between the larger ones. In the previous nitrogen experiments, three rations, "one-third," "two-thirds," and "three-thirds," with 24, 48, and 72 pounds of nitrogen per acre, respectively, have been employed. Prefacing these by a "one-twelfth" ration of 6 pounds, and a "one-sixth" ration of 12 pounds, we shall have a series of five:

Nitrogen rations.

- a.* One-twelfth ration: Nitrate of soda, 38 pounds, with 6 pounds of nitrogen.
- b.* One-sixth ration: Nitrate of soda, 75 pounds, with 12 pounds nitrogen.
- c.* One-third ration: Nitrate of soda, 150 pounds, with 24 pounds nitrogen.
- d.* Two-thirds ration: Nitrate of soda, 300 pounds, with 48 pounds nitrogen.
- e.* Full ration: Nitrate of soda, 450 pounds, with 72 pounds nitrogen.

Of this list, either all or part may be used. Thus on soils or for crops where smaller quantities are in place, *a.* *b.* and *c.* could be employed. Where more nitrogen is wanted, *c.* *d.* and *e.* would be better. If, as is not impossible, experience should show that the smaller rations are too small to be useful, it will be a very simple matter to omit them.

Phosphoric acid.—One hundred pounds of a superphosphate with 16 per cent. P_2O_5 is as little as would be often used on an acre, while 600 pounds with 96 pounds of P_2O_5 would be a large dressing. In view of the fact that general experience has led to the employing of much larger quantities of phosphoric acid than of nitrogen, the proportions within this range would be none too large to go with those of nitrogen suggested. Doubtless a series of four rations arranged as below would suffice.

Phosphoric acid rations.

- a.* One-sixth ration: 100 pounds superphosphate with 16 pounds phosphoric acid.
- b.* One-third ration: 200 pounds superphosphate with 32 pounds phosphoric acid.
- c.* Two-thirds ration: 400 pounds superphosphate with 64 pounds phosphoric acid.
- d.* Full ration: 600 pounds superphosphate with 96 pounds phosphoric acid.

Potash.—Many of the popular fertilizing mixtures are calculated to supply very small quantities of potash, not over 17 pounds per acre, while 200 pounds of muriate of potash are often used for a dressing. Taking these as extremes and dividing as before we shall have—

Potash rations.

- a.* One-sixth ration: 33 pounds muriate of potash with 17 pounds potash.
- b.* One-third ration: 67 pounds muriate of potash with 33 pounds potash.

c. Two thirds ration : 133 pounds muriate of potash with 67 pounds potash.

d. Full ration : 200 pounds muriate of potash with 100 pounds potash,

Putting the above forms together we have rations as follows :

	Nitrate of soda.	Superphosphate.	Muriate of potash.	Nitrogen.	Phosphoric acid.	Potash.
	<i>Pounds.</i>	<i>Pounds.</i>	<i>Pounds.</i>	<i>Pounds.</i>	<i>Pounds.</i>	<i>Pounds.</i>
One-twelfth ration	38			6		
One-sixth ration	75	100	33	12	16	17
One-third ration	150	200	67	24	32	33
Two-thirds ration	300	400	133	48	64	67
Full ration	450	600	200	72	96	100

DUPLICATION OF TESTS.

A very great, if not the greatest, obstacle to the success of field experiments is the unevenness of soils. The variations in the produce of different plots of apparently uniform land under the same treatment is often very surprising. An experiment in which duplicates agree as closely as could be desired is the exception rather than the rule. Cases in which the differences between plots treated alike are greater than between those treated differently, are, if anything, more common.

To get around this difficulty, numerous devices are employed. One is to test the uniformity of the plots by treating all alike the first year, and, if they vary materially, to either attempt to average duplicates so as to make the differences counterbalance, or to allow for the differences in computing the final results. One serious objection to either of these plans is the uncertainty as to the cause of the variation and to whether it will be constant in succeeding years.

Another plan consists in making the plots long and narrow, so as to equalize the differences. This, though often successful, is not always so. The ideal method would be to test the experimental areas by uniform treatment for a series of years until temporary causes of irregularity, such as came from manuring, tillage, cropping, &c., were eliminated, and to use for experiment only such as prove to be intrinsically uniform.

Where feasible, this latter plan is certainly to be recommended. But if we are to begin an experiment at once, doubtless the best way is to use small plots and duplicate the trials by using the same materials on several. This duplicating will test the uniformity and reliability of the whole experiment, and give averages which, when no untoward circumstances prevent, are pretty sure to be fairly satisfactory and are often perfectly so.

SIZE OF EXPERIMENTAL PLOTS.

Ordinarily, plots of eight square rods, one-twentieth acre, each, seem as satisfactory as any. In most cases, two plots of one-twentieth would be preferable to one of one-tenth acre. At least, such is the impression left on my mind after looking over the reports of several hundred experiments sent me for examination. Before this experience I was inclined to larger areas, but I have been surprised at the uniformity of small plots, when they are long and narrow. Some of the most satisfactory field experiments have been on plots of only four square rods. It is very common to leave a number of plots unmanured to test the uniformity of the soil, but it is a question whether this purpose is not better served by duplicating manured plots, and using not more than two or three unmanured for an ordinary experiment. Thus, for the nitrogen experiments, the most satisfactory plan I have found has been to leave one unmanured plot on each side of the experimental field, and to frequently duplicate the "basal mixture" of superphosphate and potash salt.

SPACES BETWEEN THE EXPERIMENTAL PLOTS.

Another frequent cause of inaccuracy in field experiments with fertilizers is the extension of the roots of the plants of one plot into the soil of the next one, so that the plants feed upon their neighbors' fertilizers. The roots of corn, for instance, extend laterally several feet, and, unless something is done to prevent, the plants may get so much material that does not belong to them as to vitiate the results of the experiments. The yield on an unmanured plot between two manured ones is often much larger than on another unmanured plot whose plants have not the fertilizers close at hand to draw upon. The best plan to obviate this is to leave unmanured strips between the experimental plot so wide that the roots will not reach across them. The difficulty can be helped, of course, by plowing between the plots deep enough to cut the roots.

NITROGEN EXPERIMENTS.

In planning these experiments we need to consider the questions to be studied, the forms and quantities of nitrogen to be used, and the most fitting arrangement for the experiments. The following details naturally suggest themselves:

A.—QUESTIONS ESPECIALLY NEEDING STUDY.

- I. The action of nitrogen in different forms and amounts upon the growth of plants under varying conditions of crop, soil, climate, season, &c.
- II. The feeding capacities of different plants as related to nitrogen, *i. e.*, their capacities for providing themselves with nitrogen

from natural sources, and for utilizing that furnished in the fertilizers, in so far as these capacities are indicated by effects of the nitrogenous materials upon their growth.

B.—FORMS AND AMOUNTS OF NITROGEN AND NITROGENOUS FERTILIZERS.

I. The most important forms of nitrogen are:

1. Nitric acid.
2. Ammonia.
3. Organic nitrogen.

II. Among the kinds of fertilizers containing nitrogen in these forms, the following are important:

- | | |
|--------------------------------|--------------------------------------|
| 1. Nitric acid. | 3. Organic nitrogen. |
| <i>a.</i> Nitrate of soda. | <i>a.</i> Dried blood. |
| <i>b.</i> Nitrate of potash. | <i>b.</i> Meat scrap. |
| 2. Ammonia. | <i>c.</i> Fish scrap and fish guano. |
| <i>a.</i> Sulphate of ammonia. | <i>d.</i> Leather scraps. |

III. Quantities, as above named, to wit, "one-twelfth," "one-sixth," "one-third," "two-thirds," and "full rations," or 6, 12, 24, 48, and 72 pounds per acre.

DETAILED PLANS.

In the account of nitrogen experiments above (pages 6, 8, and 9) are schedules of the kinds and quantities of fertilizing materials there employed. Judging from the results of past experience, however, those schedules would be improved by slightly altering the quantities so as to make them conform with the rations just named, and by enlarging the list of nitrogenous fertilizers to be tested.

KINDS OF NITROGENOUS FERTILIZERS.

The following will doubtless be to the purpose:

1. For nitric acid, nitrate of soda, 96 per cent. purity, with 16 per cent. nitrogen.
2. For ammonia, sulphate of ammonia, with 21 per cent. nitrogen.
3. For organic nitrogen.
 - a.* Dried blood (steam dried), with 11 per cent. nitrogen.
 - b.* Meat scrap, azotin, with 11 per cent. nitrogen.
 - c.* Fish guano, with 8 per cent. nitrogen.
 - d.* Leather scraps (finely pulverized), with 7 per cent. nitrogen.
4. For nitric acid, ammonia, and organic nitrogen together, "nitrogen mixture," consisting of nitrate of soda, 16 per cent. nitrogen; sulphate of ammonia, 21 per cent. nitrogen, and dried blood 11 per cent. nitrogen in equal parts, and containing 16 per cent., nitrogen.

QUANTITIES OF NITROGENOUS FERTILIZERS.

We may plan for each nitrogenous fertilizer a "group" with rations, as above suggested. Thus we may have nitrogen groups with quantities per acre as follows:

Nitrogen Rations.

	Ration.	Nitrate of soda.		Ration.	Sulphate of ammonia.
		<i>Pounds.</i>			<i>Pounds.</i>
NITRATE OF SODA GROUP.....	One-twelfth.....	33	SULPHATE OF AMMONIA GROUP..	One-twelfth.....	29
	One-sixth.....	75		One-sixth.....	57
	One-third.....	150		One-third.....	114
	Two-thirds.....	300		Two-thirds.....	228
	Full.....	450		Full.....	343
	Ration.	Dried blood.		Ration.	Nitrogen mixture.
		<i>Pounds.</i>			<i>Pounds.</i>
DRIED BLOOD GROUP.....	One-twelfth.....	55	NITROGEN MIXTURE GROUP..	One-twelfth.....	38
	One-sixth.....	110		One-sixth.....	75
	One-third.....	220		One-third.....	150
	Two-thirds.....	440		Two-thirds.....	300
	Full.....	660		Full.....	450

ARRANGEMENT OF THE EXPERIMENTS.

In this way such materials as may be most desirable can be selected for each experiment, and for each a group be used with all or part of the rations suggested. Future experience must show what quantities will be best. Probably, for ordinary crops in the North, the three largest rations will be well. In the South, for cotton, very likely the smaller will be preferable. At any rate, this flexibility of plan allows fair latitude of detail, and at the same time secures the uniformity needed for the tabulation and comparison of different experiments.

In some cases it will be desirable to use the nitrogenous fertilizers alone. In the majority of cases, however, the full effect of the nitrogen will not be manifested unless some other materials are added. Generally speaking, the experiment will be most satisfactory with "complete fertilizers," such as can be made by adding the nitrogenous materials to a mixture of superphosphate and potash salt, which may be designated as "mineral fertilizers" or "mixed minerals." For these, the two-thirds rations, 400 pounds of superphosphate and 133 pounds of muriate of potash, will probably be adapted to a larger proportion of the soils and crops than the mixture of 300 pounds of superphosphate and 150 pounds of muriate of potash, used in the former nitrogen experiments. Taking the basal mixture named, and adding the several rations of nitrate of soda we shall have a "Nitrate of Soda Group" of five mixtures, each mixture containing the "mixed minerals" with a nitrate of soda ration as below:

Nitrate of Soda Group:

Mixed minerals with nitrate of soda, one-twelfth ration.

Mixed minerals with nitrate of soda, one-sixth ration.

Mixed minerals with nitrate of soda, one-third ration.

Mixed minerals with nitrate of soda, two-thirds ration.

Mixed minerals with nitrate of soda, full ration.

The amount per acre and the percentages of the several ingredients in the nitrogen mixture group, for instance, would be as follows :

Nitrogen mixture group.	Fertilizing materials.			Ingredients.					
	Superphosphate, pounds per acre.	Muriate of potash, pounds per acre.	Nitrogen mixture, pounds per acre.	Phosphoric acid, pounds per acre.	Potash, pounds per acre.	Nitrogen, pounds per acre.	Phosphoric acid, per cent.	Potash, per cent.	Nitrogen, per cent.
One-twelfth ration	400	133	38	64	67	6	11.2	11.7	1.5
One-sixth ration	400	133	75	64	67	12	10.5	11.0	2.0
One-third ration	400	133	150	64	67	24	9.3	9.8	3.5
Two-thirds ration	400	133	300	64	67	48	7.6	8.0	5.8
Full ration	400	133	450	64	67	72	6.5	6.8	7.3

PRELIMINARY GROUP.

The experiment will be much more satisfactory if we know the effects of the superphosphate, potash, salt, and nitrogenous materials separately, and, inferentially, the capacity of the soil to supply the phosphoric acid and potash as well as the nitrogen. To this end we may use the materials separately, and two by two, as has been done in previous experiments, and is shown in the schedule beyond. In the experiments described above the nitrogen of the preliminary groups has been supplied in either nitrate of soda or "nitrogen mixture." Though experience has shown very little difference, probably the mixture will be the safer, and accordingly it is here recommended.

As urged above, the many sources of error in field experiments make duplicates very important. This may be effected by repeating the nitrogen groups, in which opportunity is taken to test the different forms of nitrogen, and by putting the mixed minerals on each side of each nitrogen group, thus testing the uniformity of the soil, replacing the unmanured plots, and showing more accurately the effects of the nitrogen.

To recapitulate briefly, our experimental fertilizers, as thus planned, will be arranged in groups, thus :

Partial fertilizers	Preliminary Group. Each by itself, and two by two. Thus testing the effects of ingredients separately and capacity of soil to supply them.
Complete Fertilizers.	Nitrate of soda Group. Nitrogen as nitric acid in nitrate of soda. Sulphate of ammonia Group. Nitrogen as ammonia in sulphate of ammonia. Dried blood Group. Nitrogen as organic nitrogen in dried blood. Nitrogen mixture Group. Nitrogen in the three forms named above. Nitrogen in one-twelfth, one-sixth, one-third, two-thirds, and full rations.

Other groups containing meat scrap, fish guano, Peruvian guano, leather scrap, &c., can be employed at the discretion of the experimenter. When desired, as may be the case with cotton, for instance,

half the quantities may be used, or the same quantities distributed over double the area. The preliminary groups can be omitted if necessary, the nitrogen groups used without the basal mixture, and a smaller list of rations used in each group, as may be desirable in each case. Two nitrogen sets, which can be obtained ready for use, are described beyond.

PHOSPHORIC ACID EXPERIMENTS.

In devising plans for these experiments we have to consider what questions are to be studied and what compounds of phosphoric acid are to be employed.

A.—QUESTIONS TO BE STUDIED.

The following may be regarded, at the outset at least, as among the more important:

- I. The action of phosphoric acid in different forms and amounts upon the growth of plants under different conditions of crop, soil, climate, season, &c., *e. g.*,
 1. Soluble *vs.* precipitated.
 2. Soluble *vs.* insoluble.
 3. Effects of fineness of pulverization upon the availability of insoluble phosphoric acid in bone, rock phosphate, &c.
 4. Bone *vs.* mineral phosphate.
 5. Raw bone *vs.* boiled bone; *i. e.*, bone from which gelatine has been extracted.
- II. The feeding capacities of different plants as related to phosphoric acid, *i. e.*, their capabilities of availing themselves of the supplies of phosphoric acid at their disposal in the soil, and in fertilizers, in so far as their capabilities are indicated by the observed effects of the phosphoric acid compounds.

B.—FORMS AND AMOUNTS OF PHOSPHORIC ACID AND PHOSPHATIC COMPOUNDS.

The following list seems complete enough for the present purpose:

- I. Forms of phosphoric acid :
 1. Soluble.
 2. Precipitated.
 3. Insoluble.
- II. Kinds of phosphatic compounds :
 1. Bone.
 - a.* Raw.
 - b.* Steamed.
 - c.* Bone black.
 - d.* Bone ash.
 2. Phosphatic guanos.
 - a.* Curaçoa, &c.

3. Mineral or rock phosphate.

a. South Carolina.

b. Navassa.

c. Apatite, &c.

III. Grades of fineness: The grades of fineness will naturally depend upon what the market affords. We might use, for instance:

1. Coarse.

2. Medium.

3. Fine.

IV. Quantities of phosphoric acid:

Each of the several forms may be used in different "rations," the several rations making a group, as in the nitrogen experiments.

DETAILED PLANS.

For the specific materials to furnish the phosphoric acid in the soluble and precipitated forms, the following are perhaps as well fitted for the purpose as any. Of course others will suggest themselves.

1. Soluble phosphoric acid:

a. Dissolved bone black with 16 per cent. P_2O_5 .b. High-grade superphosphate with 32 per cent. P_2O_5 .

Of the above, perhaps (a) will serve best to begin with.

2. Precipitated phosphoric acid. This may consist of—

a. High-grade superphosphate with equal weights of chalk, making a precipitated phosphate with 16 per cent. P_2O_5 .

3. Insoluble phosphoric acid. For this, bone, phosphatic guanos, and mineral or rock phosphates will be in order. Bone and South Carolina phosphate are perhaps the most important at present:

a. Fine bone dust (mesh, 40.) from steamed or raw bone with 25 per cent. P_2O_5 .b. South Carolina phosphate with 25 per cent. P_2O_5 .

QUANTITIES OF PHOSPHORIC ACID.

As already suggested we may arrange for each of the phosphatic compounds a group of four rations. Below are examples with quantities per acre:

	Ration.	Dissolved bone black.		Ration.	Precipitated super-phosphate.
		Pounds.			Pounds.
SUPERPHOSPHATE GROUP.	a. One-sixth.....	100	PRECIPITATED PHOSPHATE GROUP.	a. One-sixth.....	100
	b. One-third.....	200		b. One-third.....	200
	c. Two-thirds.....	400		c. Two-thirds.....	400
	d. Full.....	600		d. Full.....	600

	Ration.	South Carolina superphosphates.		Ration	Steamed bone.
		<i>Pounds.</i>			<i>Pounds.</i>
SOUTH CAROLINA SUPERPHOS- PHATE GROUP.	d. One-sixth.....	133	STEAMED BONE GROUP.	a. One-sixth.....	67
	b. One-third.....	267		b. One-third.....	133
	c. Two-thirds....	533		c. Two-thirds ...	267
	a. Full.....	800		d. Full.....	400

The effects of fineness of pulverization may be tested by such groups as these:

	Grade of fineness.	Ground bone.		Grade of fineness.	Phosphate.
		<i>Pounds.</i>			<i>Pounds.</i>
FINE, MEDIUM, AND COARSE BONE DUST GROUP.	Fine.....	400	FINE, MEDIUM, AND COARSE S. C. PHOSPHATE GROUP.	Fine.....	400
	Medium.....	400		Medium.....	400
	Coarse.....	400		Coarse.....	400

The details of quantities per acre and percentages of the Superphosphate group, for instance, will be:

SUPERPHOSPHATE GROUP.	Fertilizing materials.			Ingredients.					
	Nitrogen mixture, pounds per acre.	Muriate of potash, pounds per acre.	Superphosphate, pounds per acre.	Nitrogen, pounds per acre.	Potash, pounds per acre.	Phosphoric acid, pounds per acre.	Nitrogen, per cent.	Potash, per cent.	Phosphoric acid, per cent.
A, One-sixth ration.....	150	133	100	24	67	16	6.3	17.3	4.2
B, One-third ration.....	150	133	200	24	67	32	5.0	13.9	6.7
C, Two-thirds ration.....	150	133	400	24	67	64	3.5	9.8	9.4
D, full ration.....	150	133	600	24	67	96	2.7	7.6	10.9

That is to say, the Superphosphate Group would thus consist of four mixtures. Each of these mixtures will contain a "basal mixture" with nitrogen and potash each in $\frac{2}{3}$ ration (see page 20). To this basal mixture the super-phosphate is added in successive amounts, from "one-sixth ration" to "full ration," or from 16 to 96 pounds per acre.

SULPHATE OF LIME GROUP.

Since more or less of the effect of the superphosphate may be due to its sulphate of lime, a check trial with plaster as provided in the schedule on page 31 may be advisable.

The explanation of the nitrogen experiment will apply, *mutatis mutandis*, to the phosphoric acid experiment. The idea is to so arrange the

materials that each experimenter may select groups or parts of groups at his discretion and thus make up such an experiment as will be most to the purpose in the conditions under which he works.

The following list of materials and groups includes perhaps the most important, and suggests a schedule of experimental fertilizers:

Partial Fertilizers ...	{ Preliminary Group, each by itself, and two by two.	{ Thus testing the effects of ingredients separately, and capacity of soil to sup- ply them.
Complete Fertilizers.	{ Soluble phosphoric acid Group. Precipitated phosphoric acid Group. Insoluble phosphoric acid Group. Steamed bone. Insoluble phosphoric acid Group. Raw bone. Insoluble phosphoric acid Group. S. C. phosphate. Sol., Precip., and Insol. Phos. acid Group. S. C. super- phosphate. Etc., etc.	{ Phosphoric acid in one-sixth ration, one-third ration, two-thirds ration, and full ration.
	{ Raw bone Group. South Carolina phosphate Group. Etc., etc., etc.	{ Different grades of fineness.

SCHEDULES FOR EXPERIMENTS.

While experimenters will arrange their experiments at discretion, it has seemed to me desirable to suggest schedules, and, if practicable, to make arrangements to assist them in procuring the materials with the least trouble and expense. I have, therefore, drawn up schedules for three sets of experimental fertilizers, as follows:

The first, "*Nitrogen Set No. 1*," is nearly the same as used by a number of gentlemen last season. Nitrogen is supplied as nitric acid, ammonia, and organic nitrogen, in three groups with three rations, $\frac{1}{3}$, $\frac{2}{3}$, and full ration, in each. The set requires 18 plots for the fertilizers, which, with two unmanured, would make 20 plots, or, with one-twentieth acre plots, one acre of land, for the experiment. With spaces between the plots a larger area will be needed.

NITROGEN SET NO. 1.

Materials.		Amounts.	
		Acres set—for one- twentieth acre plots.	Two-acre set—for one-tenth acre plots.
		<i>Pounds.</i>	<i>Pounds.</i>
Preliminary Group ..	1. Nitrate of soda, one-third ration	7.5	15.0
	2. Superphosphate	20.0	40.0
	3. Muriate of potash	6.7	13.3
	4. { Nitrate of soda, one-third ration	7.5	15.0
	{ Superphosphate	20.0	40.0
	5. { Nitrate of soda, one-third ration	7.5	15.0
Nitrate of soda Group	{ Muriate of potash	6.7	13.3
	6. { Superphosphate. } Mixed minerals. {	20.0	40.0
	{ Muriate of potash }	6.7	13.3
	7. { Mixed minerals, as No. 6	26.7	53.3
	{ Nitrate of soda, one-third ration	7.5	15.0
	8. { Mixed minerals, as No. 6	26.7	53.3
	{ Nitrate of soda, two-thirds ration	15.0	30.0
	9. { Mixed minerals, as No. 6	26.7	53.3
	{ Nitrate of soda, full ration	22.5	45.0
6a. Mixed minerals, as No. 6		26.7	53.3

NITROGEN SET No. 1—Continued.

Materials.		Amounts.	
		Acre set—for one-twentieth acre plots.	Two-acre set—for one-tenth acre plots.
		Pounds.	Pounds.
Sulphate of ammonia Group.	10. { Mixed minerals, as No. 6	26.7	53.3
	{ Sulphate of ammonia, one-third ration	5.6	11.3
	11. { Mixed minerals, as No. 6	26.7	53.3
	{ Sulphate of ammonia, two-thirds ration	11.3	22.5
	12. { Mixed minerals, as No. 6	26.7	53.3
	{ Sulphate of ammonia, full ration	16.8	33.7
	6b. Mixed minerals, as No. 6	26.7	53.3
Dried blood Group ..	13. { Mixed minerals, as No. 6	26.7	53.3
	{ Dried blood, one-third ration	11.0	22.0
	14. { Mixed minerals, as No. 6	26.7	53.3
	{ Dried blood, two-thirds ration	22.0	44.0
	15. { Mixed minerals, as No. 6	26.7	53.3
	{ Dried blood, full ration	33.0	66.0
	6c. Mixed minerals, as No. 6	26.7	53.3

The following, "*Nitrogen Set No. 2*," is simpler, containing only the preliminary group, and a nitrogen mixture group with five rations, and one extra "mixed minerals." It has the advantage of greater simplicity, and of testing the effects of smaller quantities of nitrogen, but has the disadvantage of not duplicating the nitrogen tests. It can be greatly improved by duplicating the "nitrogen mixture" group, which, with an extra "mixed minerals," will make 18 fertilizers. With one-twentieth acre plots, this would require an acre, and make an excellent experiment.

NITROGEN SET NO. 2.

Materials.		Amounts.	
		Set—for one-twentieth acre plots.	Set—for one-tenth acre plots.
		Pounds.	Pounds.
Preliminary Group...	1. Nitrogen mixture, one-third ration	7.5	15.0
	2. Superphosphate	20.0	40.0
	3. Muriate of potash	6.7	13.3
	4. { Nitrogen mixture, one-third ration	7.5	15.0
	{ Superphosphate	20.0	40.0
	5. { Nitrogen mixture, one-third ration	7.5	15.0
	{ Muriate of potash	6.7	13.3
	6. { Superphosphate	20.0	40.0
	{ Muriate of potash	6.7	13.3
Nitrogen mixture Group.	7. { Mixed minerals	26.7	53.3
	{ Nitrogen mixture, one-twelfth ration	1.9	3.8
	8. { Mixed minerals	26.7	53.3
	{ Nitrogen mixture, one-sixth ration	3.7	7.5
	9. { Mixed minerals	26.7	53.3
	{ Nitrogen mixture, one-third ration	7.5	15.0
	10. { Mixed minerals	26.7	53.3
	{ Nitrogen mixture, two-thirds ration	15.0	30.0
	11. { Mixed minerals	26.7	53.3
	{ Nitrogen mixture, full ration	22.5	45.0
	6a. Mixed minerals	26.7	53.3

The following specifications are intended for use in ordering the fertilizers:

Specifications for nitrogen sets: Materials to be weighed and mixed with greatest possible care and accuracy, put in bags, and each bag furnished with a label stating number and contents per schedule. *Minimum* percentages as follows: Nitrate of soda, 16 per cent. nitrogen; sulphate of ammonia, 21 per cent. nitrogen; dried blood, 11 per cent. nitrogen; superphosphate (dissolved bone black) 15 per cent. soluble and 16 per cent. total phosphoric acid; muriate of potash, 50 per cent. potash.

PHOSPHORIC ACID SET.

This tests the action of soluble phosphoric acid, in dissolved bone black, precipitated phosphoric acid in a mixture of high grade superphosphate from bone and chalk, and insoluble phosphoric acid in bone from which the larger part of the organic matter has been removed. A sulphate of lime group is added as a test of the effect of the sulphuric acid and lime of the superphosphates. This includes 25 fertilizers, which with two unmanured plots would require 27 plots, or if each plot is one-twentieth acre, a little over $1\frac{1}{3}$ acres, and more if unmanured strips are left between the rows. The set can be reduced to 21 by omitting the sulphate of lime group, and to 18 by using only three rations in each phosphoric acid group.

PHOSPHORIC ACID SET.

Materials.		Amounts.	
		Regular size for one-twentieth acre plots.	Double size for one-tenth acre plots.
		Pounds.	Pounds.
Preliminary Group..	A. Nitrogen mixture	7.5	15.0
	B. Superphosphate	20.0	40.0
	C. Muriate of potash	6.7	13.3
	D. { Nitrogen mixture	7.5	15.0
	{ Superphosphate	20.0	40.0
	E. { Muriate of potash	6.7	13.3
	{ Superphosphate	20.0	40.0
	F. { Nitrogen mixture } Basal mixture {	7.5	15.0
	{ Muriate of potash }	6.7	13.3
Soluble phosphoric acid Group.	A. { Basal mixture	14.2	28.3
	{ Dissolved bone black	5.0	10.0
	B. { Basal mixture	14.2	28.3
	{ Dissolved bone black	10.0	20.0
	C. { Basal mixture	14.2	28.3
	{ Dissolved bone black	20.0	40.0
	D. { Basal mixture	14.2	28.3
	{ Dissolved bone black	30.0	60.0
Fa. Basal mixture		14.2	28.3
Precipitated phosphoric-acid Group.	A. { Basal mixture	14.2	28.3
	{ Precipitated phosphate	5.0	10.0
	B. { Basal mixture	14.2	28.3
	{ Precipitated phosphate	10.0	20.0
	C. { Basal mixture	14.2	28.3
	{ Precipitated phosphate	20.0	40.0
	D. { Basal mixture	14.2	28.3
	{ Precipitated phosphate	30.0	60.0
Fb. Basal mixture		14.2	28.3

PHOSPHORIC ACID SET—Continued.

Materials.		Amounts.	
		Regular size for one-twentieth acre plots.	Double size for one-tenth acre plots.
		<i>Pounds.</i>	<i>Pounds.</i>
Steamed bone Group.	A. { Basal mixture	14.2	28.3
	{ Bone dust	5.0	10.0
	B. { Basal mixture	14.2	28.3
	{ Bone dust	10.0	20.0
	C. { Basal mixture	14.2	28.3
	{ Bone dust	20.0	40.0
	D. { Basal mixture	14.2	28.3
	{ Bone dust	30.0	60.0
Fe. Basal mixture		14.2	28.3
Sulphate of lime Group.	A. { Basal mixture	14.2	28.3
	{ Plaster	3.8	7.5
	B. { Basal mixture	14.2	28.3
	{ Plaster	7.5	15.0
	C. { Basal mixture	14.2	28.3
	{ Plaster	11.3	22.5
Fd. Basal mixture		14.2	28.3

Besides the above set, groups like the following may be employed.

Materials.		Amounts.	
		Regular size for one-twentieth acre plots.	Double size for one-tenth acre plots.
		<i>Pounds.</i>	<i>Pounds.</i>
South Carolina super- phosphate Group.	A. { Basal mixture	14.2	28.3
	{ South Carolina superphosphate	6.7	13.3
	B. { Basal mixture	14.2	28.3
	{ South Carolina superphosphate	13.3	26.7
	C. { Basal mixture	14.2	28.3
	{ South Carolina superphosphate	26.7	53.4
	D. { Basal mixture	14.2	28.3
	{ South Carolina superphosphate	40.0	80.0
South Carolina phos- phate Group.	A. { Basal mixture	14.2	28.3
	{ South Carolina phosphate	14.2	28.3
	B. { Basal mixture	14.2	28.3
	{ South Carolina phosphate	14.2	28.3
	C. { Basal mixture	14.2	28.3
	{ South Carolina phosphate	14.2	28.3
Steamed bone Group.	A. { Basal mixture	14.2	28.3
	{ Steamed bone	5.0	10.0
	B. { Basal mixture	14.2	28.3
	{ Steamed bone	10.0	20.0
	C. { Basal mixture	14.2	28.3
	{ Steamed bone	20.0	40.0
Fine, medium, and coarse bone Group.	D. { Basal mixture	14.2	28.3
	{ Steamed bone	30.0	60.0
	A. { Basal mixture	14.2	28.3
	{ Ground bone (fine)	20.0	40.0
	B. { Basal mixture	14.2	28.3
	{ Ground bone (medium)	20.0	40.0
Fine, medium, and coarse South Caroli- na phosphate Group.	C. { Basal mixture	14.2	28.3
	{ Ground bone (coarse)	20.0	40.0
	A. { Basal mixture	14.2	28.3
	{ South Carolina phosphate (fine)	20.0	40.0
	B. { Basal mixture	14.2	28.3
	{ South Carolina phosphate (medium)	20.0	40.0
	C. { Basal mixture	14.2	28.3
	{ South Carolina phosphate (coarse)	20.0	40.0

Specifications for fertilizers of phosphoric acid set: Materials to be put up with greatest care, in bags with labels stating contents. Minimum percentages as follows: Nitrogen mixture and muriate of potash as in nitrogen experiment. Superphosphate (dissolved bone black) with 15 per cent. soluble, and 16 per cent. total P_2O_5 . Precipitated phosphate to consist of high grade superphosphates 32 per cent. and chalk in equal parts, and to contain 16 per cent. P_2O_5 . Other materials to be of good average quality.

ARRANGEMENT OF THE EXPERIMENT.

The plan herewith shows a fitting arrangement for the "Nitrogen Experiment No. 1," and illustrates how others may advantageously be planned.

NITROGEN EXPERIMENT.

Arrangement of experimental field.

With "Acre set." Each plot $\frac{1}{20}$ acre.	} Or more with unmanured strips between each two plots.
Whole field one acre.	
With "Two-acre set." Each plot $\frac{1}{10}$ acre.	
Whole field two acres.	

- | | |
|------------------------|---|
| | 0. No manure. |
| Preliminary group..... | { 1. Nitrate of soda. |
| | { 2. Superphosphate. |
| | { 3. Muriate of potash. |
| | { 4. Nitrate of soda and superphosphate. |
| | { 5. Nitrate of soda and muriate of potash. |
| | { 6. Superphosphate and muriate of potash.
"Mixed minerals." |
| Nitric-acid group..... | { 7. Mixed minerals plus nitrate of soda. One-third ration. |
| | { 8. Mixed minerals plus nitrate of soda. Two-thirds ration. |
| | { 9. Mixed minerals plus nitrate of soda. Full ration. |
| | 6a. Mixed minerals. Duplicate of No. 6. |
| Ammonia group..... | { 10. Mixed minerals plus sulphate of ammonia. One-third ration. |
| | { 11. Mixed minerals plus sulphate of ammonia. Two-thirds ration. |
| | { 12. Mixed minerals plus sulphate of ammonia. Full ration. |
| | 6b. Mixed minerals. Duplicate of No. 6. |
| Organic-nitrogen group | { 13. Mixed minerals plus dried blood. One-third ration. |
| | { 14. Mixed minerals plus dried blood. Two-thirds ration. |
| | { 15. Mixed minerals plus dried blood. Full ration. |
| | 6c. Mixed minerals. Duplicate of No. 6. |
| | 00. No manure. |

CROPS TO BE EXPERIMENTED UPON.

The kind of crop will, of course, be selected by the experimenter. Experiments are needed upon all our ordinary crops, but especially on wheat, barley, rye, oats, corn, sorghum, grass, clover, onions, potatoes, roots, and, in the South, sugar cane and cotton.

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LEVI STOCKBRIDGE

and the

Stockbridge Principle of Plant Feeding

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By WILLIAM H. BOWKER

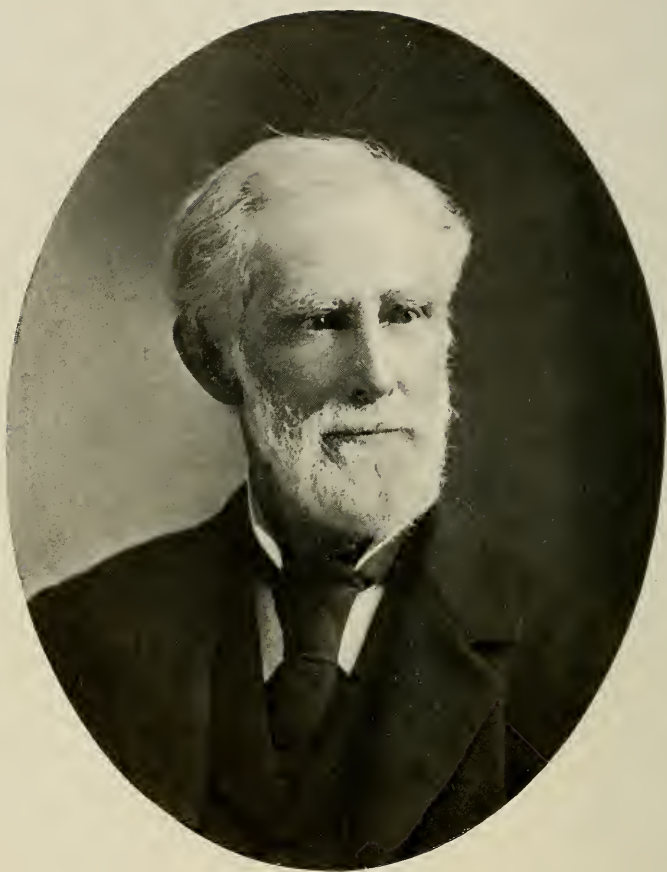
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1904

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BOSTON 1911



LEVI STOCKBRIDGE

Professor of Agriculture in the Massachusetts Agricultural College from 1871 to 1882, and President of the College from 1880 to 1882.

1820—1904

LEVI STOCKBRIDGE

BIOGRAPHICAL NOTE: Levi Stockbridge, a man of the type of Abraham Lincoln, was a farmer's son and for many years a practical farmer in Hadley, Mass. Except for such schooling as he received at the district school, and a few lectures in chemistry which he attended at Amherst College, he was self-taught. He possessed an alert mind, a retentive memory, and a marked talent for clear, forceful expression. Becoming distinguished as a leader and public speaker, he was sent for several terms to both branches of the Massachusetts Legislature. He was Massachusetts' first cattle commissioner, and in the course of his twenty-seven years' continuous service in that office he came to know nearly every farmer in the state, who looked up to and respected him. One of his greatest achievements was the quick and effective manner in which he stamped out a threatened epidemic of pleuro-pneumonia.

He was instrumental in securing for the state the Agricultural College located at Amherst, Mass., in spite of ridicule and strong opposition. He was its first farm superintendent; later, professor of agriculture, and for two years its president. During his connection with the college, at considerable personal inconvenience, he frequently endorsed the notes of the college to the local banks, thus tiding it over financial stress. He

BIOGRAPHICAL NOTE

was also "an ever-present help in time of need" to many worthy students. All the students were "his boys," and to all he was counselor and friend, and endearingly known as "Prof Stock."

Physically, he was tall and wiry, with a great capacity for work, which he never shirked. He was humorous, tactful, judicial, but outspoken; always sunny, hopeful, sane; of the right makeup to lead and teach young manhood. He sprang from the plain people and believed in them; thus he naturally abhorred a plutocracy and believed in every man's having a fair chance.

It is thought that he did as much to advance the cause of agricultural education and to popularize the chemistry of plant foods as any one man of his time. It was while he occupied the chair of professor of agriculture that he evolved the Stockbridge principle of plant feeding and the Stockbridge formulas which he freely published to the world, and which have made his name a household word in rural communities.

THE STOCKBRIDGE PRINCIPLE OF PLANT FEEDING

If I were asked what was Professor Stockbridge's greatest contribution to agriculture, I should say that it was *not* his formulas for crop feeding by which he is so widely known; for, useful as these were, they were but stepping stones to a better knowledge of the object and use of fertilizers. His greatest contribution to agriculture, as it seems to me, was his *new conception of the office of fertility* in farm economy. Up to the time of the publication of the Stockbridge formulas, the practice had been to *manure the soil* in order to restore lost fertility and to supply deficiencies in the soil, as ascertained by a chemical or crop analysis of the soil. Stockbridge saw that this method was not a practical solution of the problem, for neither chemical nor crop analysis of the soil could be relied upon as a true guide to its enrichment. The chemist disclosed too much that was misleading and the crop too little that was conclusive. But, what is more to the point, Stockbridge saw that we had taken hold of the problem at the wrong end.

A PRACTICAL SOLUTION

It was *not the soil, but the crop, that we should first consider*. We should study it and its needs, and supply it, as far as we were able, with the necessary elements of plant nutrition by the

use of properly balanced manures. In a word, he turned from the inert soil, which could not answer, to the living crop, which could, and put this question to it:

“ *What shall I supply you* in excess of what you may obtain from the soil or air by your own habits and conditions of growth to make you a perfect and profitable crop? ”

On the other hand, the farmer was asking him:

“ *What shall I use* to produce profitable crops — how much and in what form? ”

Starting, then, from the crop, with the farmer's question ever spurring him on, and with such data as he could find, he worked out his well-known formulas, which were published broadcast in 1876. And let me say here that besides being published in many agricultural papers and reports, more than half a million pamphlets containing them were distributed.

FORMULAS NOT INFALLIBLE

He did not claim that his formulas were infallible, for he anticipated and announced, what we soon discovered in practice, that they would need to be modified, as experience should point the way. They served, however, a greater purpose even than Stockbridge dreamed at the time — they centered our thought and our study on the crop. From that time on we discussed *plant food and not soil food* — plant feeding instead of soil manuring. “Feed the crop rather than the soil” was a frequent expression at that time.

It is well to observe here that crop formulas were not new. Ville and others had published

various sets. The Stockbridge formulas, however, were unique in this: that they were based not alone on the analysis of the crop, but on its power of absorption from all the sources of fertility—from soil, air, and water. Thus Stockbridge boldly prescribed:

“To produce fifty bushels of shelled corn per acre (without any stable manure) and its natural proportion of stover, *more* than the natural yield of the land, apply so many pounds each of nitrogen, potash, and phosphoric acid. Or, to produce a stated quantity of tobacco leaf of the desired color and texture, apply a stated quantity of plant food elements, preferably in the form of sulphates and nitrates.”

Here, then, for the first time, *a definite way was prescribed* to attain a definite object. It was a startling proposition, and, as might be expected, it brought ridicule from many quarters, but Stockbridge did not allow that to disturb him. He knew that the commercial farmer needed a tangible starting point. He knew that to consider the needs of the crop, the living thing, both as to amount and kind of plant food, rather than the needs of the soil, an unknown and unknowable quantity, was not only a common-sense way of meeting the problem of plant nutrition, but a very direct way of helping the farmer out of the quagmire of doubt.

INSURE THE CROP

The formulas might not be accurate; in some cases they might supply excessive amounts of plant food elements and apparently be very wasteful, yet he believed that in the end it was

better economy to apply too much and *insure a crop* than use too little and *lose a crop*. Nevertheless, as Professor Stockbridge anticipated would be the case, the fertilizers based on his formulas were modified from time to time as we gained light, chiefly by the reduction of nitrogen and the increase of phosphoric acid, as it was found that many crops were able to gather from natural sources, through bacterial action or otherwise, some part of the required nitrogen, and that an excess of available phosphoric acid would hasten maturity. It was also found that to supply the full complement of nitrogen in addition to what the crop would assimilate for itself tended in many cases to produce an unbalanced growth; yet, on the other hand, it was found that in some cases, especially where a forced growth or a tender leaf was required, an excess of nitrogen was desirable. Thus it will be seen that the crop was both the starting and the objective point. Not only its chemical needs, but its habits and conditions of growth, the object for which it was grown, and its market qualities, were all factors which influenced the composition or modification of the fertilizers; and the same factors are as potent to-day. Thus, since it was the crop that chiefly concerned Professor Stockbridge, how natural and sensible was his question: "What shall I supply you to make you a perfect and profitable crop?"

POTENTIAL FERTILITY

Let us now consider for a moment another phase of the subject, namely, the potential

fertility of the soil, or "the natural yield," to which Professor Stockbridge frequently referred. It has been known for a long time that practically all tillable soils are rich in plant food elements, and yet many of them are barren, and most of them will not produce profitable crops without the aid of manure or fertilizer.

Prof. Frederick D. Chester, of Delaware, states in an able bulletin recently published:

"An average of the results of 49 analyses of the typical soils of the United States showed per acre for the first eight inches of surface 2,600 pounds of nitrogen, 4,800 pounds of phosphoric acid, and 13,400 pounds of potash. The average yield of wheat in the United States is 14 bushels per acre. Such a crop will remove 29.7 pounds of nitrogen, 9.5 pounds of phosphoric acid, 13.7 pounds of potash.

"Now, if all the potential nitrogen, phosphoric acid, and potash could be rendered available, there is present in such an average soil, in the first eight inches, enough nitrogen to last ninety years, enough phosphoric acid for five hundred years, and enough potash for one thousand years."

In a word, potential fertility represents plant food which is so tightly locked up that it is not available for present needs and becomes available only through the process of decay and disintegration, which is too slow to meet the requirements of the commercial farmer. Stockbridge realized the situation, but instead of asking the soil how much of the potential fertility could be depended upon for each crop (a question which will never be satisfactorily answered), he went to the crop and asked it how

much it was necessary to supply for a stated yield over and above the natural yield of the land. In all cases he found it to be a very small quantity. For the corn crop, not over 200 pounds of nitrogen, potash, and phosphoric acid was necessary, which the crop would return fiftyfold (at least five tons in stalk and grain), so little to produce so much, and yet, if this little quantity of 200 pounds was not supplied, the crop would be a failure.

THE LITTLE ESSENTIAL BALANCE

It was this little essential balance of available plant food which stood between success and failure that concerned Professor Stockbridge, as it concerns every farmer to-day. Although it was small, he did not deem it wise to depend upon the potential fertility of the soil to supply it, or even any considerable part of it. For the commercial farmer it was too risky and uncertain. To insure a crop, as far as one was able, was a cardinal principle with him; not to do it was, in his eyes, almost a crime. But he felt that all these things would right themselves as we came to know more about farm crops and their environment.

THE SINGLE ELEMENT DOCTRINE

As bearing on the economy of his system of plant feeding, I want to quote here one of his apt illustrations. He said in effect:

“ In a sense the farmer is a manufacturer and the soil is his machine, into which he puts plant food, and out of which, by the aid of nature and his own efforts, he

takes his product at harvest time. If the soil machine is a good one, so much the better. If it has a balance of crop-producing power to its credit, let us preserve that balance for an emergency. Let us not draw on it for present needs."

He had no patience with the so-called *single-element doctrine*, which depends for its success on the potential fertility — no patience with the farmer who was trying to find out for himself if he could leave out any one of the three leading elements of plant nutrition (nitrogen, potash, and phosphoric acid), or how little of each he could get along with. That was a proper subject for the scientific worker to investigate, but until we knew more about it, the practical farmer, who had his living to make and bills to pay, should not tinker with it. To Stockbridge it meant, in the end, improvident farming. At best, the farmer had to take great chances, especially with the weather, — the largest factor in crop raising, over which he had no control, — but he should take no chances with the things which he could control. Among these were the amount and kind of manure which he applied to his crops. Thus, if he hoped for a stated crop he should at least fertilize intelligently for that crop. For the man who was dependent on his crops any other course was unwise. Moreover, any other course would leave the soil machine in a poorer condition than he found it. Broadly speaking, to encourage him to take out more than he put back was not only bad economy, but bad morals, and should be discouraged, for in the end it would lead to crop bankruptcy.

RAISING THE STANDARD

It is needless to say that the farmers appreciated this bold course. As Stockbridge put it, they jumped on his wagon before he was ready to start. He was indeed their prophet, who led them out of the wilderness of speculation into the light of practical methods. As might be expected, this new conception of the use of chemical manures — or plant food, as he liked to call it — not only revolutionized all our notions of fertilization, but the entire fertilizer business as well. It immediately raised the standard of commercial manures from ordinary superphosphates, containing no potash, to "complete manures," many of them rich in potash. Special fertilizers for special crops or classes of crops were brought out by various makers, and the business received a new impetus and a new recognition in the community. It was put on a sound footing, from which it can never be displaced.

STOCK FEEDING AND PLANT FEEDING

As in stock feeding we chiefly concern ourselves with the study of the animal and its needs, so in plant feeding we must make an intelligent study of *the needs of the living crop*. As we know how to feed the cow for milk or beef, so we must know how to feed the plant for leaf or seed. Not only must we know the amount of plant food to be supplied, based on crop requirements, but the form and association of the different elements must be considered; and in the study of this problem we must also continue to study the soil, its potential fertility, its physical and

chemical characteristics, and particularly the lower orders of life which it contains, the bacteria and other unseen forces. In short, we must continue our study of all the sources and forces of fertility, to the end that we may know what each contributes to the upbuilding, not necessarily of the soil, but of the crop life above the soil. Thus did Stockbridge teach and practice.

GOOD PRACTICE AND GOOD SCIENCE

As Stephenson made practical the discovery of Watts, as Singer improved upon the invention of Howe, so Stockbridge took the teachings of Liebig and Johnson, the tables of Wolf, and the experiments of Goessmann, Atwater, and Sturtevant, and applied them to practical and useful ends. While the system of plant feeding which he employed, or perhaps I should say, the method of application as prescribed in his formulas, did not appeal to the scientific mind in the beginning, it did appeal to the practical farmers, for it met their needs as no other method ever before had done. As good practice and good science must agree in the end, so I believe the scientific world is coming to agree with the practical farmer that the system and the method of application for which Stockbridge stood and labored is as truly scientific as it is thoroughly practical, and to accord him a high place among the workers for the advancement of scientific as well as practical husbandry.

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"Read not to contradict and to confute
nor to believe and take for granted, but to
weigh and consider." (Bacon.)

The Problem of Fertility In the Middle West



Address prepared by W. H. Bowker and Horace Bowker and
read by the latter at a Luncheon given to representative Bankers
and Railroad Men by the Middle West Soil Improvement Com-
mittee of The National Fertilizer Association, in Chicago
January 9, 1914.

According to 1910 Census Bulletin "Agriculture," page 18:
In the 10-year period 1900 to 1910

Total average yield of Corn in New England $26\frac{1}{2}$ bushels per acre, or 45.2 bushels or nearly 1 bushel more than the yield of 1900, at 38.8 bushels per acre, or 5.2 bushels more than the yield of 1890, at 33.6 bushels per acre. In the South, the yield of 1910 was 14.8 bushels, or nearly 1 bushel more than the yield of 1900, at 13.9 bushels, or nearly 1 bushel more than the yield of 1890, at 12.9 bushels.

Note: The yield of corn in the South is better than that in the North, but the yield of corn in the North is better than that in the South, and the yield of corn in the West is better than that in the North.

EXPENDITURES OF FARMERS FOR FERTILIZER IN 1909

1 DOT = \$5,000

How the use of Fertilizers has increased in the United States in the past Ten Years

(From U. S. Census 1910)

	1899	1909	Amount of Increase	Per cent Increase
UNITED STATES	53,430,910	114,882,541	61,451,631	115.0
New England State	4,297,705	9,405,759	5,110,054	118.9
Middle Atlantic	11,344,290	18,211,474	6,877,184	60.6
South Atlantic	22,732,670	59,621,197	36,888,527	162.3
East North Central (O., Ind., Ill., Mich.)	5,866,520	8,758,881	2,892,361	37.4
West North Central (Minn., I., Mo., N. D., S. D., Neb., Kansas)	1,407,175	983,216	-423,959 (decrease)	-30.1

East and West Compared

	Cost of Fertilizer per acre (Average)	Yield of Corn per acre (Average)
East (New England, Middle Atlantic, South Atlantic, East North Central)	45	17
West (West North Central, South West)	33	11
Ratio, using \$1 of cost of fertilizer per acre of improved land	43	

Note: The statistics printed in this map were compiled from the Census and compared with the map as printed in the Census Report.

THE PROBLEM OF FERTILITY IN THE MIDDLE WEST

We are met here to discuss fertility or commercial plant foods, the product of the plant food industry. It is the province of our industry to send its ships to the four quarters of the globe to gather fertility and to render it available for man's use. We are now tapping the air for nitrogen, of which there are 35,000 tons hanging over each acre of the earth's surface, — an exhaustless reservoir, soon to be extensively utilized to restore the nitrogen which has been sent abroad in the shape of cattle and cereals.

Liebig's Great Discovery

About seventy-three years ago a chemist, Baron Von Liebig, discovered that bone dissolved in sulphuric acid was more available for plants than the raw bone. Bone and wood ashes had been used as fertilizers for ages, but it was known that bone was slow-acting, that it did not render up its plant food readily enough. It was known that plants took their nourishment from the soil in solution, and must have most of it *during 60 days of the growing season*. It was known that bone was not soluble in water. Liebig reasoned that if it could be made soluble in water, plants would assimilate it more readily. He found by treating bone (a three-lime phosphate) with sulphuric acid, that he took away two parts of lime, forming sulphate of lime, or land plaster, and left the remaining part of lime in combination with phosphorus as a one-lime phosphate which was soluble in water, a form easily assimilated by growing crops, and which would produce an earlier and more vigorous growth. He called this product Superphosphate of Lime. It was one of the great discoveries of the ages, and the beginning of the fertilizer industry. Thus you see that chemistry is the basis of the industry.

Sources of Commercial Plant Foods

Let us consider the chemical elements in which the fertilizer industry deals. It is known that crops require some thirteen elements for their growth, ranging from nitrogen to iron. It is known that soil and air are abundantly supplied with most of them; that through continuous cropping, without adequate returns, most soils are deficient in nitrogen, phosphorus, potassium, and in some cases lacking in lime and sulphur; that as a rule, the three which we need to supply, *the great trio*, are nitrogen, phosphorus and potash.

Thus we have searched the world for sources of phosphorus, contained in phosphate of lime. We have found enormous quantities of phosphates in the Carolinas, in Florida, in Tennessee, and now in Wyoming and Montana. We have mined this phosphate, washed it, and ground it, and following the discovery of Liebig, we have dissolved it and converted it into a superphosphate, now popularly known as Acid Phosphate.

We have searched the earth for potash to take the place of the potash which we used to get in wood ashes, and so far we have found only one available source, in Germany, and that seems to be inexhaustible. But it is a monopoly, and we are made to pay much more for it than we should pay.

We have searched the world for nitrogen, the most costly element of plant food, and we have found it in the enormous nitrate deposits of Chili, and in the coal deposits of Pennsylvania, Ohio, and Illinois, or wherever there is soft coal which can be used for coking purposes. This we are recovering in the form of sulphate of ammonia, the use of which should be encouraged, for the reason that it is not only an excellent source of nitrogen, but it is a home source, lying right here under our feet, by the use of which we can build up our agriculture and keep at home some part of the millions we are now sending abroad for nitrogen, — an economic proposition from any angle you view it.

We also find nitrogen in the by-products of our packing houses and fisheries, — in the immense quantities of tankages, waste meat and waste fish, which are converted into fertilizers. We also find it in seed meals, like cotton seed and linseed; but these and the tankages are now being used so extensively for feeding purposes that they are not a dependable source.

Finally in our search for nitrogen we come to the atmosphere, the greatest source of all. Recent discoveries are rendering available the nitrogen of the atmosphere in a chemical known

as Cyanamid, and also in Nitrate of Lime, but the utilization of atmospheric nitrogen at present depends upon a high degree of heat, which can be generated only by means of an electrical current. Where cheap water power is abundant and an electrical current can be generated at low cost, which cannot be sold for lighting or manufacturing purposes, at that point it can be utilized to extract nitrogen from the atmosphere. A plant is in successful operation at Niagara Falls and one in Norway. Also plans are under way for developing the great water powers in the Blue Ridge mountains for this purpose. A scheme is also reported in the newspapers to utilize Grand Falls in Labrador for extracting atmospheric nitrogen.

Another source of nitrogen is the leguminous crops grown by farmers, whereby soil bacteria are utilized. It is known that no plant can thrive *above* the earth unless smaller plants, known as bacteria, are growing *in* the earth, — in other words, a lower order of life, which yields up its life to a higher order in the shape of farm crops, which in turn yield up *their* life that men and animals may exist, thus rounding out a marvelous cycle, the connecting links of which we are just beginning to study, and in a small way, to comprehend.

So we see that the fertilizer industry is something more than mixing a few ingredients together with a shovel on a barn floor. If you men have to deal with commercial, labor and engineering problems, we have all these, and in addition we must know something of the applied sciences, such as chemistry, mineralogy, botany, and bacteriology. If one will take the time to go through a modern fertilizer plant and note its furnaces, lead chambers, retorts and towers, its crushers and grinders, he will see that it is something more than a mixing mill and warehouse.

Lawes, the Founder of the Industry

We spoke of Liebig being the inventor of Superphosphate of Lime, the basis of the business, yet the real founder of the fertilizer industry, as an industry, was Sir John Lawes of England. He claims to have discovered superphosphate simultaneously with Liebig, but whether he did or not, he was the first man to begin the manufacture of mineral phosphates (the Cambridge coprolites of England) into superphosphate or acid phosphate, and to add nitrogen to it in the shape of sulphate and muriate of ammonia. Later, potash in the shape of German salts was added, making what is now called the "complete fertilizer."

Lawes made a large fortune in the business, a portion of which he devoted to the maintenance of an experiment station on his own estate, Rothamsted, which he inherited. For more than sixty years he conducted a series of experiments with all sorts of fertilizers and fertilizing materials and reported them so accurately and so fairly, no matter whether for or against commercial fertilizers, that they have been accepted as authoritative throughout the world. His work was so good that he was knighted by Queen Victoria and since his death the Rothamsted station has been taken over by the Government, and is now conducted as a public experiment station, much like our state experiment stations.

Now the fertilizing industry the world over has copied Lawes, and is making exactly the same things which he made, and which the Lawes Manure Company is making today in England, so if we are not making good things the blame must rest with Lawes, whom we have imitated. By some critics complete fertilizers have been called "soil stimulants" and "patent soil medicines," and for that reason the public is sometimes warned against them. If they are stimulants like rum why should Lawes be praised for manufacturing them, and we, in this country, condemned for doing the same thing? To laud the one and condemn the other is inconsistent, to say the least.

The Evolution of the "Complete" Fertilizer

Let us consider what a so-called complete fertilizer really is, containing the three leading elements, nitrogen, phosphorus, and potash. It is an evolution. Liebig started with ground bone, which contains nitrogen and phosphate of lime. He took practically a thousand pounds of bone and added a thousand pounds of sulphuric acid, the thousand pounds of bone originally containing 4% of nitrogen and 20% of phosphoric acid. When he added the thousand pounds of sulphuric acid he divided the result by two and the final product of dissolved bone contained, therefore, approximately 2% of nitrogen and 10% of phosphoric acid. In the trade today it is what is called a 2-10 goods.

What was the next step? Somebody added some concentrated potash, and then we had the "complete" fertilizer containing nitrogen, soluble phosphorus, and potash, or practically a 2-8-2 goods, *dissolved bone with potash*, which some of our critics affect to call a soil or plant stimulant.

Milk is a complete food, containing the three leading elements of food; namely, protein, in the shape of cheese, fat in the shape of cream, and sugar in the shape of milk sugar. Would you call it a stimulant because of that fact?

There is no such thing as a stimulant to plants in the sense that alcohol is a stimulant to man. Fertilizers are available plant food. They encourage and sustain growth because they are largely soluble in water, and are easily assimilated by plants, as milk is easily assimilated by children. Fertilizers are "liquid assets" which are as essential in the soil as in business. Crops are living things; they want what they want *as* and *when* they want it; failing of it they "go broke." There are some who go so far as to say that anything is a stimulant to plants which makes them grow. In that sense, water, the greatest known solvent, is a stimulant, and sunshine is a stimulant, and the electric light may yet prove to be a stimulant. However, to satirize fertilizers by classing them with rum is neither scientific nor fair.

The "Filler" in Fertilizers

A great many people think fertilizers contain "filler" or extraneous material. They are encouraged to think so by those interested in the sale of chemicals produced in and outside of this country. When Liebig added 1,000 pounds of sulphuric acid to 1,000 pounds of bone, he practically had a ton of half the strength of the original bone, but it had been rendered soluble hence much more valuable. In the process there is some shrinkage, perhaps 10% or 200 pounds, which gives room to add potash in the form of a German potash salt, and then the ton is rounded out and the mixture is a "complete fertilizer," containing the three elements, — nitrogen, *available* phosphorus, and potash, *but where is the filler*—that bugbear, that scarecrow, that thing which is held up by some of our critics to discredit our wares? There was no filler in Liebig's Dissolved Bone or in Lawes' "Complete Fertilizer" made from dissolved bone, for there was no room for any; and there is practically no filler in fertilizers today, for the reason that there is little or no room for any. Moreover, there is another and more potent reason, namely, it costs money to assemble and prepare extraneous matter, even common sand, when by proper balancing of materials it is not necessary. A chemist who figured his formulas so that it cost 25 cents or even 10 cents a ton "to fill up" would soon lose his job.

Did it ever occur to you that only 15% of pure milk is solids or *food*, and that the remaining 85% is water? Can you separate the water from the milk and still have a white, limpid fluid? The water in milk is the "normal water of composition" which holds and carries the actual nourishment of milk. So in fertilizers, take nitrate of soda, one of the most popular fertilizer chemicals ; 100 lbs. contains 15 pounds of nitrogen; the remaining 85 pounds is the "normal oxygen, soda and water of composition." Take the most concentrated fertilizer chemical salt in use, namely, muriate of potash. It contains only 50 pounds of potash in the hundred pounds.

Finally, take one of the most concentrated complete fertilizers which the industry puts out; it contains but 25% of actual plant food in a ton, or 500 pounds of nitrogen, potash, and phosphoric acid added together. What is the remaining 1,500 pounds? Naturally one not familiar with chemistry thinks it is so called "filler" but it is nothing of the kind. It is made up of organic matter, salts, alkalis and acids, which are the carriers or containers of plant food, as the water of milk is the natural carrier of the food of milk, as the fibre of meat is the natural carrier of the protein and fat of meat. And right here it is well to observe that one of the medium grades of fertilizer on the market, 3-8-4, which equals 15 units of plant food to a ton, is exactly the same number of units that nitrate of soda contains. Does anyone claim that nitrate contains any filler in the popular sense of that term because it carries only 15 units or 300 pounds of plant food in a ton?

It may be urged that by using concentrated chemicals one can make the same grade with two-thirds of the bulk. So he can in some cases, but such mixtures would cake and would not be drillable in a machine. Moreover, they would not supply the forms of plant food which crops need. Besides, the exclusive use of these concentrated chemicals would displace just so much by-product plant foods, which it is good to use, both from the standpoint of economy and from that of making stable, drillable goods. No sound economist or wise agronomist advises the exclusive use of concentrated chemicals any more than he would advise the exclusive use of concentrates in the feeding of live stock.

We have gone into this matter with some detail because the imputation of the use of fillers is so often thrown up against the industry to injure it. Now while we do not say that fillers are never

used, it is the exception rather than the rule, and the exceptions are usually where they are needed as "conditioners" and in that case they are usually such materials as not infrequently contribute to the sum total of plant food. Fillers, in the shape of extraneous matter, would be disclosed in the analysis, which rarely occurs. *As a matter of fact, they exist chiefly in the imagination of the critics.*

Barren (?) East and Fertile (?) West Compared

It has been said that where fertilizers have been used longest in the East, there the soil is worn out. The Crop Census does not show it. On the contrary, where attention is paid to rotation of crops, and to keeping up the humus, the Census shows that the East is producing, even of the staple crops, much more per acre than is grown in the Middle West*. Moreover, where fertilizers have been used extensively and intelligently, there the soils are increasing in fertility and agriculture is prospering. In Europe they find *it pays to make a fertile soil still more fertile* by the use of chemical fertilizers. Gov. Herrick, our minister to France, writes:

"All the states along the Atlantic seaboard now use commercial fertilizers. Eventually there will not be an acre in the Nation that cannot profitably use fertilizers. If used in the smallest European proportions of \$6 to the acre, the aggregate sum bulks so large as to stagger the imagination."

Fertilizers Serve Other Purposes

Commercial fertilizers, in addition to supplying plant food, serve other purposes which are often lost sight of. Because they supply this food in soluble, active forms, they improve quality; as in the case of grains, they stiffen the straw and fill out kernels; but what is quite as important, they hasten maturity, reducing the percentage of soft corn or wheat. Oftentimes they are the best *crop insurance* a farmer can employ.

In New England, commercial fertilizers were first used as "starters," as concentrated foods are used to start a calf to an early vigorous maturity. Before the days of dissolved bone they could not raise corn successfully in New Hampshire. The seasons, as a rule, were not long enough to mature it. Now almost every county in the state has its corn king who raises more corn per acre than the average yield of the Corn Belt.

*See Addenda.

New Hampshire, according to the Census, produced in 1910 46 bushels of corn to Illinois' 39 bushels per acre, and Iowa's 37 bushels.

Thirty years ago they came near giving up the growing of wheat in the Genesee Valley in New York, because of the ravages of the Hessian fly. Someone tried commercial fertilizer and found it hastened the growth of the wheat plant so that it got ahead of the fly and for years the wheat industry in the Genesee Valley was preserved. Now commercial manures are used extensively in that valley on every variety of crop.

Sole Source of Fertility

In the East, from the use of fertilizers for a particular purpose on a particular crop, their use has extended to all crops and in many cases they have become the sole source of applied fertility. Take for example the potato crop. It was discovered that better potatoes could be grown on fertilizers than on stable manure and the result is that in Aroostook County, Maine, more than 25,000,-000 bushels of potatoes are grown exclusively on high grade commercial fertilizer. They are producing in that county 300 bushels per acre against 92 in the Middle West. The county reminds one of Iowa. Much of the land is recently cleared and all the soil is naturally fertile; but they find it pays to make it still more fertile by the liberal use of fertilizers. It is conservatively estimated that 60,000 tons are used each year in this one county. The bankers in Aroostook County will tell you that fertilizers have put that county on the map commercially as well as agriculturally.

A still better illustration is the cotton crop of the South. Any banker or railroad man will tell you that the South is absolutely dependent on the fertilizer industry to grow the cotton crop. It is true that they are not producing as much cotton per acre as they ought to produce and will produce with improved seed, crop rotation, and better methods of cultivation. It is also true that they are not producing in the South as much corn per acre as is being produced in Illinois and in New England, and we in New England are profitably producing on our so-called "exhausted farms" by the use of fertilizers, almost *50% more per acre* than is being produced in the Corn Belt, or 45.5 bushels in New England to 32.8 bushels in the Corn Belt.

But the South will never produce corn so long as it can produce *cash crops* such as cotton, sugar, rice, and citrus fruits. And you in the Middle West ought to be thankful that it will not. It is

your place to grow the corn, the cattle, the wheat, and the oats, which the South cannot so well produce. Let each latitude grow the crops naturally adapted to it and in the end it will make for better conditions the country over.

Some Jolts and Some Boosts

New England has prided herself upon being advanced, but recently she has been jolted out of her complacency, the last severe jolt being the collapse of her railway systems. She has waked up to find that Chicago is competing with her in music and art, Indiana in literature, and Wisconsin in progressive legislation, while the Middle West is sending men to reorganize her railroads. The Middle West claimed for years, and justly so, that agriculturally it was the richest section in the country, but the last Census gave her also a bad jolt. It showed that she was falling behind in agricultural production, and in the number of resident farm owners. Viewed from the outside it would appear that the two most important questions in the Middle West are, how to increase production and how to deal with the tenant farmer.

A Boost,—J. J. Hill's Experiments

James J. Hill has conducted some wonder-working experiments with fertilizers, which have not received the attention they deserved in the West. Is it because the West does not want to admit that it needs rejuvenation, or is it because she is complacent? Hill showed in one season, by the use of fertilizers, that he could double the yield of cereals in the Middle Northwest. It matters not at this time whether it was done at a profit. The important thing is to demonstrate that yields can be doubled by a certain treatment. Thirty-six years ago Bell demonstrated that he could talk over a wire from one room to another. Today we know the result. The fertilizer industry has nothing to fear from such experiments as Hill's, even if all of them are not at first commercially successful. It has nothing to fear from any experiments provided they are carried on without bias and by men who have no hobby to ride.

Will it Pay? No Longer an Academic Question

The value of commercial plant food has passed beyond the experimental stage in Europe and in the eastern part of this country. Why not accept the testimony of seventy-five years

at Rohamsted, of fifty years at Halle, and of thirty years in Georgia and in Maine. I sometimes wonder if the agricultural teachers and writers in the West are not standing in the way of agricultural progress by still considering as an academic question the value and need of fertilizers. The question is not — Are commercial fertilizers good and useful? — *but will it pay to use* them as James J. Hill has done in his part of the country. To my mind, Mr. Hill has answered the question, "will it pay?" in the affirmative. By the use of a little over \$5 worth of fertilizer per acre he practically doubled the yield of wheat, oats and barley, and you can figure whether it paid or not. I wish that other railway officials might follow his splendid example.

The Hill experiments are along the lines of intensive agriculture. The fertilizer industry stands for intensive agriculture, which includes good seed, thorough cultivation, rotation of crops, cover crops, and the plowing in of green crops wherever it is necessary to keep up the humus of the soil. Its best fields are where the best agricultural practice is in vogue.

The Industry vs. Criticism

The industry knows its own shortcomings and it is not unmindful of the benefits of criticism, but in the face of criticism and opposition it has grown in the last forty years from half a million to nearly 7,000,000 tons. In the last five year Census period the use of complete fertilizer increased 104 per cent.

Criticism and ridicule which retards the day of the introduction and use of commercial plant foods in the Middle West serves no economic purpose. It is as shortsighted as it is unsound. In Europe, government-paid officials and teachers who are unfair to legitimate industry are the exception. State and Federal paid teachers who call fertilizers "soil stimulants," and "patent soil medicines," who imply that they are composed of "fillers," and who deliberately exaggerate the profits of the industry to discourage their use, are not fair, to say the least. They neither serve the true interests of agriculture nor promote the welfare of the Nation which employs them.

It would seem that an industry which has stood the test of three-quarters of a century, that conserves every pound of plant food it can find, that delves in the earth and taps the air in order that more abundant and cheaper fertility may be supplied, is an industry that is quite worth while.

ADDENDA

SOME JOLTS AND SOME BOOSTS

Taken from the Census and from Experiments

According to 1910 Census Bulletin "Agriculture," page 18:

The average yield of Corn in New England *increased* from 39.4 bu. per acre to 45.2 bu. or nearly 15%

In Illinois the yield *stood still* at 38.8 bu.

In Iowa it *dropped* from 39.1 bu. to 37.1 bu. or 5%.

In Kansas it *dropped* from 27.8 bu. to 19.1 bu. or 31%.

In Nebraska it *dropped* from 28.8 bu. to 24.8 bu. or nearly 14%.

In Missouri it *dropped* from 28.1 bu. to 26.9 bu. or 4%.

It is suggested that better seed, better cultivation and added fertility from some source would improve conditions, as the same things have done in New England and in Old England.

JAMES J. HILL'S

Wonder Working Experiments with Fertilizers

(Condensed from World's Work, April, 1913)

In one year Mr. Hill demonstrated in the middle North West that he could practically double the yield of wheat, barley and oats by the use of fertilizers. The experiment was tried on five-acre plats on 151 farms (755 acres in all) scattered along the Great Northern route in Minnesota and North Dakota, the most extensive practical experiment the world has ever seen, as follows:

Average of the Great Northern Plats With Fertilizer		U. S. Census Average of Minnesota and No. Dakota without Fertilizer	Increase
Wheat	30 bu. per acre	Wheat 15.8 bu. per acre	14.2
Barley	47 " " "	Barley 21.9 " " "	25.1
Oats	71 " " "	Oats 31. " " "	40.

The grain in each case from the fertilizer plats was much superior in quality and brought a higher price. Each acre received \$5.39 worth of fertilizer. It can easily be calculated whether the increased yield paid or not. It is the experience the world over where commercial plant foods are used intelligently, that not only are larger yields of *better quality* obtained, but the land steadily increases in productiveness.

WHEAT EXPERIMENTS

In England, Pennsylvania, Ohio and Illinois

Dr. Cyril G. Hopkins of the University of Illinois gives the following statistics in "Science," October 3, 1913:

England — As an average of 60 years where wheat has been grown year after year on the same land at Rothamsted:

Unfertilized Land produced	12.6 bu. per acre
Farm Manure produced	35.4 " " "
Commercial Plant Food produced	37. " " "

Pennsylvania — As an average of 24 years the wheat yields at Pennsylvania State College, when grown in a four-year rotation, varied as follows:

Unfertilized Land produced	10.1 bu. per acre
Farm Manure produced	24.1 " " "
Commercial Plant Food produced	24.8 " " "

Ohio — As an average of 19 years the wheat yield at the Ohio Experiment Station, the wheat being grown in a five-year rotation with clover, timothy, corn and oats on five different series of plots, so that every crop might be represented every year.

Unfertilized Land produced	10.2 bu. per acre
Farm Manure produced	21.7 " " "
Commercial Plant Food produced	26.9 " " "

Illinois — On five Experiment fields of the University of Illinois, located in different parts of the state the following results with wheat are given for 1913.

Unfertilized average of the 5 fields	13.1 bu. per acre
Fertilized with Organic Manures, Limestone, Phosphorus and Potassium, average of 5 fields	32.3 " " "

Average increase	19.2 " " "
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NEW ENGLAND AND THE MIDDLE WEST COMPARED

The following figures are based on the U. S. Census

	Corn (Av. Bu.) per acre	Wheat (Av. Bu.) per acre	Potatoes (Av. Bu.) per acre
<i>New England</i> , using \$1.30 worth of fertilizer per acre of improved land, produces	45.	24.	177.
<i>The Middle West States</i> , using 4 cents worth of fertilizer per acre of improved land, produce	33.	17.	92.
<i>Maine</i> , using \$1.72 worth of fertilizer per acre of improved land, produces	43.	25.	210.

